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A SYSTEMATIC REVIEW OF AUGMENTED REALITY'S IMPACTS ON EDUCATION

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ABSTRACT

Augmented Reality (AR) has significant potential to enhance education by providing immersive and interactive learning experiences. This study conducts a Systematic Literature Review (SLR) to explore the challenges and opportunities in AR implementation for education. Findings indicate that while AR improves student engagement and comprehension of abstract concepts, its adoption in developing countries is hindered by limited infrastructure, inadequate teacher training, and unsupportive policies. In contrast, developed nations have successfully integrated AR due to stronger infrastructure, comprehensive educator training, and supportive policies. To facilitate AR adoption in developing countries, investments in infrastructure, teacher capacity-building, and policy support are essential. These findings highlight the need for collaboration among governments, educators, and technology developers to address challenges and expand access to AR-enhanced education.

Keywords: Augmented Reality, Educational Technology, Teacher Training, Digital Divide.

INTRODUCTION

Augmented Reality (AR) is increasingly recognized as an innovative educational tool due to its ability to merge real-world elements with digital information in an interactive and immersive way (Akçayır & Akçayır, 2017). Research has shown that AR enhances students' understanding of abstract concepts, facilitates experiential learning, and bridges the gap between theory and practice (Chen & Tsai, 2019). In developed countries, AR adoption in education has expanded rapidly, supported by well-established technological infrastructure, widespread access to high-quality devices, and structured teacher training programs (Radianti et al., 2020). However, in developing nations, AR

implementation faces significant barriers, including inadequate infrastructure, low educator readiness, and a lack of policies supporting AR integration in education (Cai et al., 2018). Despite AR's potential to improve educational quality, these challenges continue to fuel debates that require further research.

In the context of developing nations, AR has the potential to play an even more critical role than in developed countries, as it can help mitigate limited access to educational resources. Many schools in developing regions still rely on traditional teaching methods, which often struggle to effectively convey abstract concepts (Radianti et al., 2020). The lack of laboratories, interactive teaching materials, and learning aids makes it difficult for students to fully grasp complex subjects. AR offers an innovative solution by enabling simulation-based learning experiences that can be accessed anytime and anywhere (Liu et al., 2020). Additionally, AR can expand educational access for students in remote areas, where shortages of teachers and learning facilities remain prevalent (Nguyen & Tran, 2019). However, compared to developed countries, where infrastructure and regulations already support educational technology, developing nations continue to face substantial challenges in integrating AR into the curriculum.

One of the primary obstacles to AR adoption is limited technological infrastructure. Many schools in developing nations lack access to AR-compatible hardware, such as tablets, computers, and AR headsets, which remain expensive and unaffordable for most institutions (Yilmaz, 2017). Furthermore, unstable internet connectivity poses a significant barrier to utilizing online-based AR applications (Bower et al., 2014). Beyond infrastructure, educator readiness is another major challenge. The lack of training programs for teachers hampers the effective use of AR in classrooms—not only in terms of technical skills, such as operating AR devices and applications, but also in pedagogical strategies for integrating AR into effective learning experiences (Wang et al., 2019). Many teachers in developing countries lack access to professional development programs focused on technology-enhanced learning, leading to the underutilization of AR as a passive demonstration tool rather than an interactive and engaging learning resource (Bower et al., 2014).

Insufficient policy and regulatory support further hinder AR adoption in education across developing nations. In developed countries, technology-driven education policies are often integrated into national strategies, with incentives for schools that embrace innovative technologies. Conversely, in many developing nations, the absence of clear policies on AR integration has resulted in sporadic and unsustainable implementation efforts (Alzahrani & Binsuwaidan, 2021). Limited government funding for educational technology investments, coupled with low awareness among policymakers regarding AR's benefits, exacerbates these challenges. Understanding policy barriers and identifying strategies for regulatory improvements are therefore crucial in promoting the successful adoption of AR in education.

Chart 1. AR Implementation Challenges in Developing Countries
Source : Yilmaz, R. (2017); Bower, M., et al. 2020; Liu, D., et al. 2020

While previous research has extensively explored the benefits of AR in enhancing the learning experience, studies examining the challenges of its implementation in developing nations remain limited (Radianti et al., 2020). Additionally, existing research on educator readiness primarily highlights the lack of training but often fails to distinguish between gaps in technical proficiency and pedagogical expertise in AR integration (Bower et al., 2014). To address this gap, this study categorizes the challenges of AR adoption into four key dimensions: (1) technological infrastructure, including limited access to AR-compatible hardware and unstable internet connectivity; (2) educator readiness, referring to disparities in technical and pedagogical skills necessary for effective AR utilization; (3) local context, highlighting the lack of AR content aligned with national curricula; and (4) cost and accessibility, which encompass financial constraints limiting access to AR devices.

Building on this framework, the study also synthesizes solutions identified in the literature, such as the development of affordable AR technology, competency-based teacher training programs, and the need for regulatory frameworks that better support AR adoption in education. To deepen the understanding of these issues, this study aims to address three key research questions: (1) What challenges do educators face in integrating AR technology into the formal education curriculum in developing nations? (2) How does AR implementation impact student engagement, motivation, and understanding in developing country? (3) What solutions have been proposed in the literature to help educators overcome barriers to AR adoption? By answering these questions, this research seeks to provide actionable insights that facilitate the effective integration of AR technology in education systems within developing regions.

METHOD

This study employs the Systematic Literature Review (SLR) method, following established guidelines to identify relevant studies and provide a

comprehensive overview of the research topic. The review process includes formulating the research problem, defining inclusion and exclusion criteria, and selecting reputable databases to ensure data integrity and reliability. The data for this study consist of articles indexed in Google Scholar, with specific inclusion and exclusion criteria: (1) exclusion of literature review articles, (2) selection of studies published within the last 10 years (2015–2025), (3) focus on the application of Augmented Reality (AR) technology, and (4) relevance to the challenges and solutions for AR implementation in developing countries. These criteria ensure that the selected studies provide relevant and up-to-date insights into the topic.

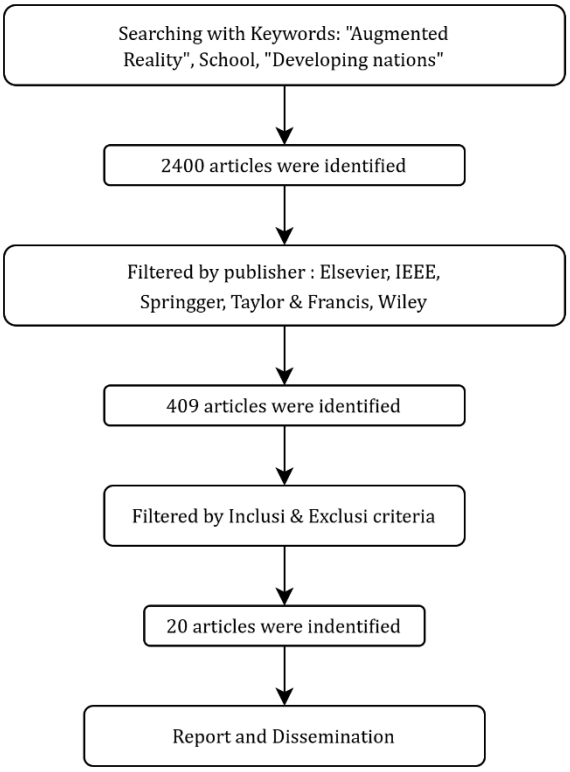

Chart 2. *The steps of obtaining data*

The research process initially identified 2,400 articles meeting the search criteria. To ensure quality and relevance, filtering was conducted by prioritizing articles from leading international publishers, including Elsevier (ScienceDirect), IEEE Xplore, Springer, Taylor & Francis, and Wiley Online Library, narrowing the selection to 409 articles. Further screening based on the predefined inclusion and exclusion criteria resulted in 20 key studies that were comprehensively analyzed. The findings from these 20 papers provide critical insights into the research questions: (1) challenges educators face in integrating AR into formal education curricula, (2) the impact of AR on student engagement, motivation, and understanding, and (3) proposed solutions to overcome barriers to AR adoption. Each of these studies contributes unique perspectives and empirical evidence, helping to construct a well-rounded analysis of AR implementation in developing nations.

RESULTS AND DISCUSSION

Based on the analysis of various academic journals related to the research topic, Table 1 provides a comprehensive summary of key findings. This table presents essential details from each study, including the source, subject area, research method, AR application used, as well as the benefits and challenges identified. By systematically categorizing these elements, the table offers a structured overview of how AR has been applied in different educational contexts, highlighting both its advantages and the barriers to its implementation.

The summarized findings reveal patterns across various studies, demonstrating that AR consistently enhances student engagement, motivation, and conceptual understanding. However, challenges such as limited technological infrastructure, lack of educator readiness, high costs, and inadequate policy support

remain significant obstacles, particularly in developing nations. This synthesis of literature serves as a foundation for addressing the research questions, providing insight into the current landscape of AR in education and identifying potential strategies for overcoming implementation challenges.

Table 1. Related articles

No	Author(s)	Research Method	Opportunities	Challenges
1	(Ji & Li, 2024)	Analysis Discussion	Development of political teaching methods	Difficulties in implementing contemporary ideologies
2	(Abou-Shouk & Soliman, 2021)	Mediation Model	Increase brand awareness and customer loyalty	Varied adoption rates of gamification
3	(Almaqtari et al., 2024)	Empirical Study	Improved audit efficiency	Infrastructure limitations in developing country
4	(Micheline, X. Yu and C. Sun., 2023)	Case Study	Enhanced learning experience	High cost and accessibility
5	(Amir, Mohd & Ahmad, Vasim & Arora, Jigyasha & Ballabh, Samita & Verma, Tulika. (2023))	Exploratory Study	Increase student engagement	Difficulty in technology integration
6	(Badshah, M. M. Nasralla, A. Jalal and H. Farman., 2023)	Qualitative Study	Efficiency in technology-based learning	Limitations of supporting policies
7	Ramesh, Sujatha & Krishnaier, Natarajan. (2020)	Literature Study	Education in remote areas	Infrastructure limitations
8	(Majumder; A. Goswami., 2021)	Case Study	Online learning adaptation	Resistance to technological change
9	(Baig & Jamil, 2020)	Literature Study	Digital education solutions	Digital divide
10	(P. Vichare *et al*., 2023)	Experimental Study	Effectiveness of the flipped classroom method	Teacher and student readiness
11	(Singh, N. Sengar, D. Das and S. C. Misra,. 2022)	Conceptual Study	Improving village development	Implementation of technology in rural areas
12	(Thomas, Rettin & Ajith, K. & Shivdas, Avinash & .R, Harikrishnan,. 2024)	Quantitative Study	Facilitate access to information	Ethical and reliability concerns
13	(Riaz and J. Muhammad,,. 2015)	Literature Study	Interactivity in learning	Lack of training for educators
14	(Zulfiqar, Fatima & Raza, Rehan & Khan, Muhammad & Arif, Muhammad & Alvi, Atif & Alam, Tanvir,. 2023)	Case Study	Enhance the learning experience	Cost and infrastructure barriers
15	(Alam, Syed alam & Saif Ahmed,. 2023)	Literature Study	Greater access to education	Internet and device limitations
16	(Latchem, Colin., 2018)	Experimental Study	Visualize abstract concepts	High development costs
17	(Salmi, H., Thuneberg, H., & Vainikainen, M. P., 2016)	Systematic Review	Improved learning outcomes	Adaptation difficulties by educators
18	(Mensah , Ronald Osei., 2023)	Quantitative Study	Improved academic performance	Technology access gap

19	(Baxter, Gavin & Hainey, Thomas., 2023)	Literature Study	Improved concept understanding	Technical and financial constraints

Table 1 highlights the diverse applications of emerging technologies such as Augmented Reality (AR), Virtual Reality (VR), Artificial Intelligence (AI), and gamification in the education sector, each serving different objectives. While the adoption of these technologies has been shown to improve the quality of education and streamline processes such as digital audits, various challenges persist in their implementation. Among these technologies, AR stands out for its ability to enhance student engagement, motivation, and conceptual understanding, yet its effectiveness varies across different education levels.

Research findings indicate that AR is particularly effective in primary education, where it helps visualize abstract concepts through simple interactive elements. At the tertiary level, AR applications become more complex, often used in laboratory simulations, engineering, and medical education. For instance, Silva et al. (2023) found that elementary students grasp spatial topics such as geography and biology more effectively through AR-based learning. Meanwhile, Baek et al. (2024) highlighted AR's role in enhancing laboratory learning in engineering and medicine, requiring more advanced hardware and software. However, key challenges hinder AR adoption, particularly in developing nations, including infrastructure limitations, integration difficulties, and adoption barriers due to high costs and lack of technical expertise.

Despite its potential, the implementation of AR and other emerging technologies requires careful planning, policy support, and substantial resources. The studies analyzed in this review predominantly focus on countries with robust technological infrastructure, such as the United States and Europe, creating a regional bias in existing findings. As a result, these conclusions may not fully reflect the realities in developing nations, where limited infrastructure, financial constraints, and inadequate educator training pose significant obstacles to adoption. Moreover, most AR applications have been developed for subjects such as science and mathematics, leaving other disciplines underexplored. To bridge this gap, further research is needed to address these challenges, expand AR applications to a broader range of subjects, and ensure equitable access to educational technology worldwide, particularly in developing regions. The following table provides a structured summary of studies on AR implementation in the education sector.

Tabel 2. AR in the education sector

Author	Methodology	Research Findings	Educational Level
Haryadi & Pujiastuti (2023)	Surveys, quantitative analysis	72% of students are more motivated to use AR compared to traditional methods	Elementary Education
Cao & Yu (2023)	Experimentation, quantitative analysis	40% increase in understanding of laboratory practice material using AR	Higher Education

Silva et al. (2023)	Experiments, case studies	AR improves the understanding of abstract visuals in geography and biology	Primary & Secondary Education
Baek et al. (2024)	Case studies, AR simulations	AR is effective in medical education for studying human anatomy	Higher Education (Medical)

Challenges in AR Implementation in Developing Countries

The adoption of Augmented Reality (AR) in education faces significant challenges, primarily due to technological infrastructure limitations. Many schools lack access to AR-compatible devices, such as smartphones and tablets, while inadequate internet connectivity further hinders AR-based learning (Baig & Jamil, 2020). Additionally, educator readiness remains a concern, as many teachers have never received formal AR training, making integration into teaching practices difficult (Bower et al., 2014).

Another major obstacle is the shortage of skilled human resources. The effective use of AR requires technical expertise, yet many educators lack the necessary skills to manage and integrate AR applications into their curriculum (Liu et al., 2020). High costs associated with purchasing hardware and developing localized AR content further restrict adoption. Most existing AR technologies are designed for developed countries, making them less compatible with local curricula in developing nations (Mensah, 2023). Studies show that AR enhances student engagement and comprehension, particularly in subjects requiring complex visualization (Haryadi & Pujiastuti, 2023; Cao & Yu, 2023). However, without tailored content and adequate support, AR's full potential in developing countries remains underutilized (Mkwizu & Bordoloi, 2024).

Strategies for AR Implementation in Education

To enhance AR adoption, technological infrastructure development is crucial. Governments and private sectors must collaborate to improve internet access and provide affordable AR devices through funding initiatives (Abou-Shouk & Soliman, 2021). Educator training programs should also be prioritized, integrating both technical and pedagogical aspects to ensure effective AR utilization in classrooms (Badshah et al., 2023).

Developing locally relevant AR content is essential to align with national curricula and cultural contexts (Alzahrani & Binsuwaidan, 2021). Policy support plays a key role, with regulations encouraging ethical and responsible AR adoption while providing incentives for institutions implementing AR-based learning (Baxter & Hainey, 2023). Studies confirm that AR enhances student engagement, motivation, and conceptual understanding, particularly in STEM subjects (Silva et al., 2023; Erwis et al., 2024). By addressing these challenges, AR can serve as a transformative tool in enhancing education quality in developing countries.

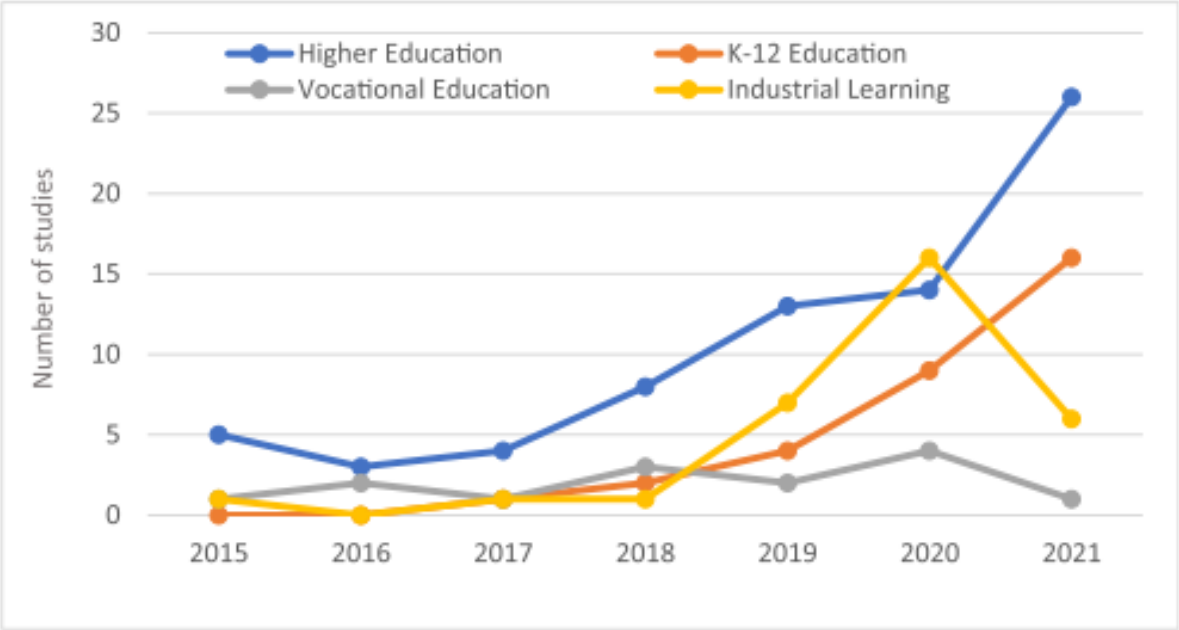

Chart 3. Distribution of VR and AR studies
Source: (Sakr & Abdullah, 2024)

Solutions Identified in the Literature

To enhance the implementation of Augmented Reality (AR) in education within developing countries, several strategic measures are recommended. These include expanding access to technology infrastructure, training educators, developing localized AR content, and establishing strong policy support. Addressing these barriers can transform AR into a powerful tool for creating a more inclusive, interactive, and innovative education system. Additionally, collaboration among stakeholders, including governments, academia, and the technology sector, is essential for ensuring the successful integration of AR in education (Almaqtari et al., 2024).

One of AR's key advantages is its ability to enhance teaching efficiency by simplifying complex concepts. For instance, in medical education, AR simulations allow students to explore human anatomy virtually, reducing reliance on cadavers while improving learning efficiency (Baek et al., 2024). This approach not only accelerates knowledge acquisition but also enhances practical understanding, making AR a valuable asset in education and professional training.

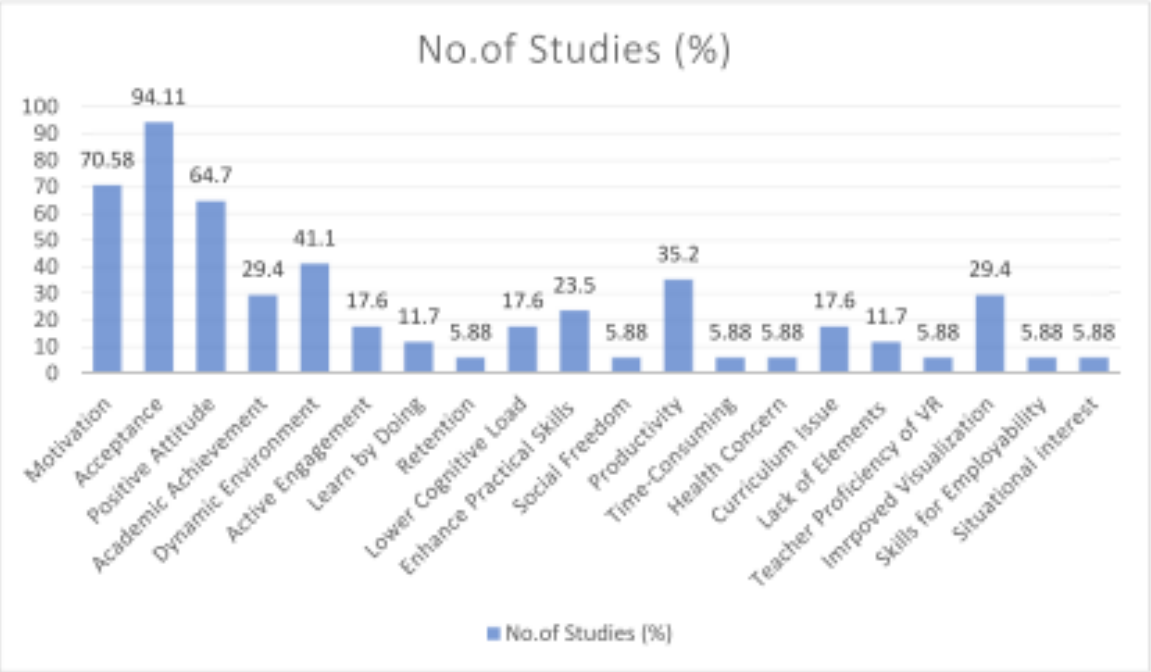

Chart 4. Percentage Chart of Studies on AR/VR Aspects
Source: (AlGerafi et al., 2023)

DISCUSSION

The adoption of Augmented Reality (AR) in education has followed different trajectories in developed and developing countries, with various challenges still hindering its implementation in developing regions. In developed countries, AR has been successfully integrated into curricula due to better infrastructure, broader access to advanced devices, and supportive education policies. For instance, the United States and Japan have effectively implemented AR in both higher education and elementary schools, enhancing student engagement and comprehension of abstract concepts through interactive and immersive experiences (Bower et al., 2014). Conversely, developing countries face significant barriers, particularly limited technological infrastructure. Many educational institutions lack access to essential hardware (e.g., tablets and high-spec computers required for AR applications) and struggle with unstable internet connectivity (Nguyen & Tran, 2019). These disparities contribute to a widening digital divide, exacerbating inequalities in education quality between developed and developing nations.

Beyond infrastructure challenges, insufficient teacher training is a major obstacle to AR adoption in developing countries. Many educators lack the technical skills to effectively integrate AR into their teaching. According to Wang et al. (2019), teachers often feel unprepared due to the absence of continuous, pedagogically relevant training. In contrast, developed countries have implemented structured training programs, ensuring that educators can seamlessly integrate AR into their lessons. Additionally, while AR offers transformative learning experiences, over-reliance on technology may reduce direct

teacher-student interaction, potentially impacting social and emotional skill development (Yilmaz, 2017). Furthermore, privacy and data security concerns must be carefully addressed, as AR applications often collect user data, raising risks related to student privacy if clear policies are not in place. Developing countries can learn from the experiences of developed nations by prioritizing infrastructure improvements, educator training, and supportive policies. A structured, locally tailored approach is crucial to ensuring AR's effective and responsible integration into education, maximizing its benefits while mitigating potential risks.

Tabel 3. Differences in education in developed and developing countries

Factors	Developed Country	Developing Country
Access AR Device	More extensive, with stronger technological infrastructure (tablets, high-spec computers)	Limited, many schools still rely on old devices and lack of specialized AR devices
Internet Connectivity	Stable and fast, supports cloud-based AR applications	Unstable, slowing down the maximum adoption of AR
Teacher Training	Structured and continuous training program	Limited training, often only focused on the basic use of technology
Adoption of the AR Curriculum	Already implemented in many schools with customized modules	Only just starting to be adopted on a limited basis, mostly still in the experimental phase
Education Policy	Policies that support the adoption of technology in education (e.g., digitization policies)	There is no specific policy; AR adoption is often limited to pilot projects or grants.
Success Rate of AR Implementation	High, proven to be effective in increasing student engagement and understanding	Low, limited to the implementation of low-tech conversations and learning

Table 3 highlights the differences in AR adoption between developed and developing countries. In developed nations, the widespread availability of devices, stable internet connectivity, and supportive policies has facilitated the seamless integration of AR into education. Conversely, in developing countries, challenges such as limited infrastructure, inadequate educator training, and unsupportive policies remain significant barriers to widespread AR adoption.

CONCLUSION

Augmented Reality (AR) holds great potential to enhance education in developing countries, yet its implementation is hindered by technological limitations, insufficient teacher training, high costs, and a lack of localized content aligned with national curricula. Addressing these challenges requires comprehensive teacher training programs that equip educators with both technical and pedagogical skills to integrate AR effectively. Collaboration with technology developers is also crucial to creating culturally and contextually relevant AR content. Additionally, policymakers must prioritize investments in technological infrastructure, including affordable AR devices and improved internet connectivity, particularly in remote areas. Supportive policies—such as

financial incentives for educational institutions and data privacy regulations—are essential to fostering responsible AR adoption. Future longitudinal studies should focus on the long-term impact of AR on learning retention, as well as its potential in underrepresented disciplines and informal education settings. Through cross-sector collaboration between educators, policymakers, and technology providers, AR can become a powerful tool in creating a more interactive, inclusive, and innovative education system, ultimately bridging the digital divide in developing countries

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