

Title Regulatory Strategy for Utilizing Augmented Reality as a Visual Aid in Science Learning in Rural Elementary Schools

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Abstract

This study examines the integration of Augmented Reality (AR) as a visual aid in science learning at rural elementary schools in Indonesia. Rural schools face limited access to digital media and weak infrastructure, creating barriers for students in understanding abstract scientific concepts. The aim of this research is to formulate a regulatory strategy that supports sustainable AR adoption in rural education. A mixed methods sequential exploratory design was used. The quantitative phase involved a survey of 90 respondents (45 teachers and 45 students) to identify readiness and barriers. The qualitative phase included interviews with teachers, principals, and education officials, as well as analysis of local and national education policy documents. Findings reveal that the main obstacles include poor internet access (78%), lack of teacher training (72%), and limited AR devices (68%). A small-scale trial in two schools showed a significant improvement in student learning outcomes, with average test scores increasing from 65.2 to 78.5 ($t(54)=6.72$, $p<0.001$). The study concludes that a four-pillar regulatory framework—comprising infrastructure and access, teacher capacity building, curriculum alignment, and monitoring & evaluation—is essential to enable equitable and sustainable AR integration. This framework provides practical recommendations for policymakers and contributes to advancing digital inclusion in rural education.

Keywords:

Regulatory Strategy; Augmented Reality; Visual Learning Tool; Science Education; Rural Schools

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INTRODUCTION

The rapid development of educational technology has reshaped science instruction by offering new ways to visualize and interact with complex concepts. Among these innovations, Augmented Reality (AR) has attracted significant attention because it allows abstract scientific phenomena to be represented in three-dimensional, interactive forms. Studies in well-resourced contexts have shown that AR can enhance student engagement, motivation, and conceptual understanding (Bower et al., 2020). However, in rural areas of developing countries, such as Indonesia, the Philippines, India, and parts of Africa, the adoption of AR faces serious challenges related to infrastructure, teacher readiness, and regulatory clarity (Cabrera et al., 2021; Rana, 2020; Mutisya, 2022). While AR offers many advantages, it is not without limitations. Issues such as potential distraction,



usability challenges, and frequent technical breakdowns may hinder its effective use in classrooms (Bower et al., 2020). These contrasting realities highlight the urgent need for contextual strategies and regulatory frameworks to guide the equitable implementation of AR in rural schools.

In Indonesia, the disparity between urban and rural education is stark. According to the Ministry of Education and Culture (2024), approximately 60% of elementary schools in rural areas lack access to digital learning tools and stable internet connections. Furthermore, a study by the Indonesian Association of Educational Technology (ATPI, 2024) revealed that less than 10% of rural schools have attempted to implement AR, and only a small fraction—under 5%—were able to sustain its use due to infrastructural constraints and absence of supporting policies. This situation highlights a pressing need for a structured and context-sensitive regulatory framework that can guide schools and educators in adopting AR effectively and sustainably.

The lack of clear and adaptive regulations concerning AR integration in the educational curriculum represents a critical barrier. Most rural schools operate without any formal policy on the use of emerging technologies. Teachers are often left to navigate technological integration independently, leading to inconsistent implementation and missed opportunities to harness AR's full potential. Regulatory support is vital for standardizing implementation procedures, ensuring equitable access to digital tools, and providing training and professional development for educators.

Several international studies have shown the benefits of AR in science education. Research by Egista and Mustofa (2025) indicates that students using AR in physics classes achieved a 40% improvement in concept comprehension compared to traditional methods. Moreover, Uno (2024) found that AR-based learning materials significantly increased student engagement and motivation. However, these studies are predominantly situated in urban contexts or technologically advanced schools. The challenge now is to translate these benefits into rural educational environments, which requires a tailored approach that accounts for local limitations and needs.

The Indonesian government, through the National Research Master Plan (RIRN 2017–2045), has prioritized digital transformation in education. This includes encouraging the development of educational technologies and promoting their adoption across all educational levels. However, without supportive regulation at the grassroots level, such national policies often fail to reach and benefit schools in remote and underdeveloped regions. Therefore, a bottom-up strategy that aligns national objectives with local realities is essential.

This study addresses the gap between policy and practice by proposing a regulatory strategy specifically designed to support the use of AR in science learning at rural elementary schools. It investigates the challenges faced by schools and educators, evaluates the current state of AR usage, and formulates practical policy recommendations. The research employs a mixed methods approach, combining quantitative surveys to assess general trends and barriers with qualitative interviews and document analysis to gain in-depth insights into policy gaps and implementation needs.

The objectives of this study are threefold: (1) to identify the infrastructural, pedagogical, and policy-related barriers hindering AR integration in rural elementary schools; (2) to explore teachers' and administrators' perceptions and experiences with AR; and (3) to develop a regulatory framework that supports effective, equitable, and sustainable use of AR in science education.

The novelty of this research lies in its focus on regulatory aspects rather than solely on technological or pedagogical interventions. By emphasizing policy development, this study contributes to the broader discourse on educational equity and digital inclusion. It also offers a model that can be adapted to other contexts with similar educational challenges.

Ultimately, this study aims to bridge the digital divide in science education by enabling rural schools to harness the power of AR. With appropriate regulatory support, AR has the potential to transform how students in underserved areas engage with science, thereby improving learning outcomes and fostering a more inclusive education system.

METHODS

This study employed a mixed methods sequential exploratory design to formulate a regulatory strategy for integrating Augmented Reality (AR) into science education in rural elementary schools. The design allowed for both statistical breadth and contextual depth, combining quantitative surveys and qualitative interviews with document analysis.

Quantitative Phase

The quantitative phase involved the administration of structured questionnaires to 90 respondents, consisting of 45 elementary school teachers and 45 students from rural schools in the Tilamuta District, Indonesia. The instrument included 20 Likert-scale items that assessed technology infrastructure, teacher readiness, student experience, and perceived barriers to AR adoption.

Prior to data collection, the questionnaire underwent pilot testing with 15 participants from a different district to assess its reliability and clarity. The resulting Cronbach's Alpha coefficient of 0.82 indicated satisfactory internal consistency. Data were collected through in-person visits and analyzed using descriptive and inferential statistics. Frequency distributions and mean scores were used to identify dominant barriers, while paired-sample t-tests were conducted to examine the statistical significance of pre-test and post-test differences in student learning outcomes.

Qualitative Phase

The qualitative phase consisted of semi-structured interviews with 10 school principals, 15 teachers, and 5 local education officials. These interviews explored policy awareness, implementation experiences, and regulatory needs. Interviews were recorded, transcribed, and analyzed thematically.

In addition, document analysis was conducted on 12 relevant policy documents at the national and district levels, including the *National Research*

Master Plan (RIRN 2017–2045), local education regulations, and digital transformation guidelines. Documents were selected based on three criteria: (1) relevance to elementary education and digital learning, (2) scope of policy (national or local), and (3) publication period between 2017–2024.

Limitations

It is acknowledged that the relatively small sample size (N=90) and focus on one district limit the generalizability of the findings. However, the data provide an important exploratory foundation for understanding regulatory challenges and contextual needs in rural Indonesian schools.

RESULTS & DISCUSSION

RESULTS

1. Demographic Profile of Respondents

The quantitative phase of this study involved 90 respondents consisting of 45 teachers and 45 students from eight elementary schools in the rural Tilamuta District, Indonesia. The teacher respondents were predominantly female (62%) with an average of 11.4 years of teaching experience. Most teachers were between the ages of 30 and 45, and 78% had never received formal training in educational technology or Augmented Reality (AR) integration. Among the students, the majority (67%) were in grade six and aged between 11 and 12 years. All student respondents came from public schools with limited digital resources and unstable internet connectivity.

The demographic composition highlights the unequal access to digital competency development between rural and urban educators. Teachers in Tilamuta generally expressed a strong willingness to use AR tools but lacked the knowledge and regulatory clarity to do so. Students, while enthusiastic about using digital tools, reported limited device ownership—only 41% had access to smartphones or tablets at home, and even fewer (29%) had internet data packages for online learning.

2. Infrastructure and Readiness Levels

Descriptive analysis of the questionnaire data revealed several key barriers to AR adoption in science learning. As summarized in Table 1, the top five challenges identified by teachers and students were poor internet access (78%), lack of AR equipment (68%), absence of teacher training (72%), unclear policy or guidance on AR use (64%), and limited technical support (59%).

Table 1. Major Barriers to AR Integration in Rural Schools (N=90)

Barrier	Frequency (n)	Percentage (%)
Poor internet access	70	78%
Lack of AR equipment	61	68%
No teacher training	65	72%
Unclear policy on AR use	58	64%
Limited technical support	53	59%

Field observations and infrastructure audits confirmed that six out of eight participating schools lacked adequate computer facilities. Only two schools possessed functioning projectors, and none had AR-compatible headsets or tablets. These findings

corroborate previous studies emphasizing digital inequity in Indonesian rural education (Prasetyo & Lestari, 2023; Hasanah & Yani, 2023). The absence of foundational infrastructure significantly restricts the implementation of technology-enhanced learning.

3. Teacher and Student Perceptions

Teachers' responses indicated that 83% were "interested" or "very interested" in adopting AR if provided with training and official permission. However, qualitative interviews revealed that most teachers viewed AR as a "luxury" tool rather than a practical teaching aid due to its technical complexity. Several teachers noted uncertainty about the legality of using free AR apps in classrooms, reflecting the absence of clear local regulation.

Students, conversely, demonstrated high enthusiasm for AR-assisted science learning. They perceived AR as "fun," "realistic," and "easier to understand." Nevertheless, 71% of students reported having difficulty accessing devices, and 63% mentioned that their schools lacked adequate digital infrastructure. These results suggest that while motivational readiness exists, structural readiness remains insufficient—an issue consistent with research in comparable rural contexts such as the Philippines and India (Cabrera et al., 2021; Rana, 2020).

4. Effectiveness of AR-Based Trials

To empirically assess the potential of AR integration, two volunteer schools participated in pilot classroom trials using AR-based science materials. The applications *Human Anatomy 4D* and *Merge Cube* were selected due to their offline functionality and compatibility with low-spec Android devices.

A total of 55 students participated in the trial, focusing on the topic "Human Organ Systems" within the science curriculum. Students completed pre- and post-tests measuring conceptual understanding. The mean pre-test score was 65.2 (SD=7.1), while the post-test mean increased to 78.5 (SD=6.8), yielding a mean gain of 13.3 points. A paired-sample t-test indicated that this improvement was statistically significant, $t(54)=6.72, p<0.001$.

Additionally, classroom observation rubrics rated by teachers showed an increase in student engagement from 2.8 to 4.1 on a 5-point scale. Teachers observed that students were more active in asking questions and making connections between visualized organs and real-life phenomena.

Despite the positive outcomes, technical limitations were reported. Several devices failed to load AR content smoothly, and inconsistent internet connectivity delayed lesson preparation. One teacher remarked, "We are motivated to use it, but we need official training and reliable Wi-Fi."

These findings demonstrate that AR can enhance learning outcomes and engagement when properly supported but also emphasize the critical role of infrastructure and teacher readiness.

5. Policy Awareness and Regulatory Gaps

The qualitative interviews with 30 participants (teachers, principals, and district officials) revealed a substantial lack of awareness regarding national or local policies governing AR use in schools. Only **17% of teachers** and **20% of local education officials** reported being aware of any relevant policy documents. None of the principals had received formal circulars or guidelines addressing AR or immersive media integration.

Document analysis confirmed that national-level frameworks, such as the *Indonesian National Research Master Plan (RIRN 2017–2045)*, promote digital transformation but do not translate into actionable local policies. There is no existing *Standard Operating Procedure (SOP)* or regulation that specifies how schools may adopt,

evaluate, or procure AR tools. This absence of regulatory clarity contributes to hesitation among educators who fear potential violations of copyright, data protection, or safety regulations when using AR applications.

6. Synthesis of Findings

The combined quantitative and qualitative findings reveal that AR implementation in rural elementary schools faces three interrelated challenges: (1) infrastructural deficiencies, (2) lack of teacher competence and confidence, and (3) absence of supporting policy frameworks. While students show strong enthusiasm, the absence of systematic planning and clear regulation limits the potential for long-term sustainability.

Discussion

1. Overview of Findings

This study confirms that Augmented Reality (AR) can substantially enhance science learning outcomes and engagement among rural students when properly implemented. The statistically significant improvement in students' post-test performance (mean gain of 13.3 points) indicates that AR can make abstract concepts more tangible. These results align with findings by Yulian et al. (2022) and Febrianto and Aeni (2024), who reported similar increases in comprehension and motivation among elementary students exposed to AR media.

However, these benefits are contingent upon infrastructure, pedagogical readiness, and supportive regulation—factors that remain underdeveloped in rural Indonesia. This is consistent with the argument of Cheng, Liu, and Lin (2023) that the absence of clear governance mechanisms often hinders the scalability of AR initiatives.

2. Comparison with Prior Studies

The current findings resonate with international experiences from other developing countries. In the Philippines, Cabrera et al. (2021) found that AR improved engagement but suffered from “connectivity poverty” in rural provinces. Similarly, Rana (2020) reported that rural Indian schools struggled with insufficient teacher training and inconsistent digital infrastructure, resulting in sporadic AR adoption. In Kenya, Mutisya (2022) emphasized that community-based resource centers could bridge infrastructure gaps if supported by localized policy.

Compared with these studies, the Indonesian context demonstrates both similarities and unique features. Unlike India and Kenya, where NGO-led initiatives often fill regulatory gaps, Indonesia's education system remains highly centralized. As a result, rural schools depend heavily on top-down policy implementation, making regulatory reform a prerequisite for AR adoption.

3. Policy Implications

The results clearly indicate that technological innovation alone cannot ensure equitable digital transformation. The absence of legal clarity discourages teachers from experimenting with AR in classrooms. Hence, this study proposes a four-pillar regulatory framework to guide systematic integration:

1. Infrastructure and Access — Prioritize government investment in broadband connectivity and AR-compatible devices, especially in 3T regions (*terdepan, terluar, tertinggal*). Partnerships with telecom providers and EdTech startups could reduce costs and ensure sustained access.
2. Capacity Building — Institutionalize professional development for teachers through certification programs in AR pedagogy. Following Bower et al. (2020), training should emphasize not only technical competence but also instructional design principles.

3. Curriculum Alignment — Integrate AR modules into national learning standards (Kurikulum Merdeka) to ensure consistency and sustainability. Pilot mappings in this study showed that AR-supported lessons matched 78% of the existing *Kompetensi Dasar* (Basic Competencies).
4. Monitoring and Evaluation (M&E) — Develop standardized observation checklists and reporting tools for local education offices. Continuous feedback loops, including reflective journals and usage logs, can ensure adaptive improvement and accountability.

Such a framework aligns with recommendations by Cheng et al. (2023), who highlight the importance of regulatory coherence in scaling AR initiatives across East Asia.

4. Educational Significance

The study underscores AR's pedagogical potential as a *visual equalizer*. Students who traditionally struggle with abstract content—such as human anatomy—demonstrated significant improvement when exposed to interactive 3D visualization. Similar findings were observed by Kurniawan and Wulandari (2024), who found that AR-assisted lessons improved comprehension and curiosity among Indonesian primary learners.

However, consistent with Bower et al. (2020), this study warns against the “novelty effect,” where early enthusiasm may decline if AR is not pedagogically integrated into long-term instructional design. Teachers require not just access to technology but structured guidance to connect AR experiences to measurable learning outcomes.

5. Addressing Limitations and Future Research

This study's scope—limited to 90 respondents in one district—restricts generalizability. Future research should involve larger, multi-district samples and include longitudinal data to track the sustainability of AR use over time. Additionally, while this research employed pre–post testing and descriptive analysis, more sophisticated statistical models (e.g., regression analysis or structural equation modeling) could further clarify causal relationships between teacher readiness, infrastructure quality, and learning outcomes.

Another limitation lies in the untested scalability of the proposed regulatory model. Pilot studies should examine how local governments and school districts interpret and apply the four-pillar framework in practice.

6. Broader Implications for Digital Equity

This research contributes to the broader discourse on digital inclusion in education. Without adequate regulation and infrastructure, rural schools risk further marginalization. The findings advocate a bottom-up policy approach that empowers local education offices to adapt national frameworks to local conditions—a strategy echoed by Ramadhani and Sulistyowati (2023).

The case of Tilamuta District reveals how teachers' motivation alone cannot overcome systemic barriers. Effective regulation must function as both an enabler and a safeguard—ensuring equitable access while maintaining ethical and safety standards in the use of emerging technologies.

7. Synthesis and Conclusion of Discussion

Overall, the results provide a comprehensive understanding of the conditions necessary for successful AR integration in rural elementary science education. The combination of quantitative and qualitative data illustrates a coherent pattern:

1. Technological access is a prerequisite, not a guarantee of success.
2. Teacher professional capacity is the linchpin connecting innovation to practice.

3. Regulatory clarity determines sustainability and ethical compliance.

By situating Indonesia's experience within the broader context of developing nations, this study extends the international dialogue on digital transformation and educational equity. The proposed regulatory strategy offers a pragmatic pathway for bridging the gap between national digital aspirations and on-the-ground realities in rural schools.

CONCLUSION

This study concludes that Augmented Reality (AR) has significant potential to transform science learning in rural elementary schools by enabling students to visualize and interact with abstract scientific concepts. Through mixed methods research involving 90 respondents from the Tilamuta District, this study found that AR not only improved students' comprehension and engagement but also exposed systemic challenges in Indonesia's rural education ecosystem.

Quantitative results revealed that AR-based learning produced a statistically significant increase in post-test performance ($M = 78.5$) compared to pre-test scores ($M = 65.2$), $t(54)=6.72$, $p<0.001$. Teachers also observed substantial growth in classroom participation and curiosity among students. However, these benefits were constrained by persistent barriers, including inadequate digital infrastructure, limited teacher competence, and lack of regulatory clarity.

The qualitative data illuminated the absence of specific policies guiding AR integration. While national frameworks such as the *Indonesian National Research Master Plan (RIRN 2017–2045)* emphasize digital transformation, there is no derivative or operational guideline at the school or district level. This policy vacuum results in inconsistent implementation, leaving teachers uncertain about procedural, ethical, and technical aspects of AR use.

To address these gaps, this study proposes a four-pillar regulatory strategy that encompasses (1) Infrastructure and Access, (2) Capacity Building, (3) Curriculum Alignment, and (4) Monitoring and Evaluation. These pillars collectively provide a holistic framework for enabling sustainable and equitable AR adoption in rural education.

1. Infrastructure and Access should prioritize the provision of affordable AR-compatible devices, reliable internet connectivity, and shared digital learning centers.
2. Capacity Building must focus on continuous teacher professional development, integrating AR pedagogy into pre-service and in-service teacher training programs.
3. Curriculum Alignment requires embedding AR learning modules into the national science curriculum (*Kurikulum Merdeka*), ensuring coherence between digital innovation and learning objectives.
4. Monitoring and Evaluation (M&E) should establish accountability mechanisms through regular performance reviews, teacher reflections, and digital usage analytics.

By implementing these pillars, local governments and educational authorities can bridge the gap between technological innovation and educational equity. Policymakers must also consider the bottom-up adaptation of national strategies, empowering district education offices to contextualize digital policies to local realities.

While this study provides valuable empirical evidence, it also acknowledges several limitations. The sample size ($N=90$) and focus on a single district limit generalizability. Future research should expand to multiple provinces, employ larger samples, and incorporate longitudinal designs to evaluate long-term effects of AR on learning outcomes and teacher practice. Moreover, action research collaborations involving teachers as co-researchers could generate context-specific strategies for sustained AR integration.

In conclusion, AR represents a promising tool for bridging the digital divide in science education, but its success depends on systemic readiness rather than technological novelty. Through coherent regulation, targeted capacity development, and equitable access, AR can move from isolated innovation to a cornerstone of inclusive, future-ready education in Indonesia and other developing contexts.

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