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Augmented Reality Implementation in Financial Regulatory Education for Indonesian High School Students

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Abstract

This study developed and validated AR-based learning materials for Financial Services Authority (OJK) education among Indonesian tenth-grade students. Using a mixed-methods research and development approach with the ADDIE model, the study involved 40 students selected through purposive sampling for needs assessment incorporating Technology Acceptance Model constructs. An Android-based AR application was developed using Unity 3D engine and ARCore SDK, integrating interactive 3D visualizations with comprehensive OJK educational content. Expert validation was conducted by content and design specialists using structured evaluation rubrics. The needs assessment revealed strong student support for AR integration, with 67.5% expressing positive attitudes toward AR-based learning materials. A significant positive correlation ($r = 0.734$, $p < 0.01$) was found between media diversification and learning motivation. Technology readiness showed high perceived usefulness ($M = 4.2$, $SD = 0.8$) but moderate perceived ease of use ($M = 3.1$, $SD = 0.9$). Expert validation demonstrated high content validity (87.5%, CVI = 0.875) and acceptable design quality (77.8%, DQI = 0.778). The application successfully integrated four main OJK content modules with AR functionality, including interactive 3D organizational structure visualization. Findings provide strong empirical support for AR technology adoption in financial literacy education, validating constructivist and multimedia learning theories. The study establishes a replicable framework for AR educational material development, supporting continued educational technology innovation.

Keywords: Augmented Reality, Financial Literacy Education, Technology Acceptance Model, Educational Technology, Financial Services Authority

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INTRODUCTION

The digital transformation of educational systems worldwide has created unprecedented opportunities for innovative pedagogical approaches, particularly in addressing complex conceptual learning challenges that traditional methods struggle to overcome (Bower et al., 2014; Wu et al., 2013). Within this evolving landscape, financial literacy education faces distinctive pedagogical challenges in engaging contemporary learners with abstract regulatory concepts that often appear disconnected from their immediate experiences (Lusardi & Mitchell, 2014; OECD, 2020). The integration of Augmented Reality (AR) technology presents significant potential for transforming these educational challenges into engaging,

interactive learning experiences that can enhance both student motivation and conceptual understanding.

Recent empirical evidence demonstrates the transformative potential of AR technology across diverse educational contexts. It was found that collaborative, interactive, and immersive Virtual and Augmented Reality (VAR) learning environments significantly enrich students' learning experiences, making substantial contributions to learning effectiveness (Lee et al., 2022). This finding is supported by a mixed-methods study which revealed that AR technology enhances students' motivation and interaction with learning content in science education (Cai et al., 2022).

Furthermore, another mixed-method study showed that the application of AR increased students' learning interest (Lo et al., 2021). While another study provided experimental evidence showing that the use of AR increased learning motivation, academic outcomes, and the effectiveness of collaborative learning (Lu et al., 2022).

The psychological and cognitive benefits of AR implementation extend beyond academic performance measures. There are experimental studies that reveal that, the use of AR significantly affects students' perceptions and engagement with technology, which has a positive impact on students' self-efficacy (O'Connor & Mahony, 2023). This finding is supported by research showing that, the Augmented Reality Integrated STEM Preschooler (ARISP) module significantly increased student engagement, motivation, and problem-solving skills among early childhood students (Wang et al., 2024). Additionally, another study used a mixed-method quasi-experimental design to demonstrate significant improvements in students' academic performance, motivation, and attitudes compared to a control group, while increasing engagement and interactive learning experiences (Ruiz Muñoz et al., 2024).

Indonesia's commitment to enhancing national financial literacy has positioned the Financial Services Authority (Otoritas Jasa Keuangan - OJK) as a critical educational component within secondary economics curricula (Otoritas Jasa Keuangan, 2021). However, the complex institutional nature of financial regulatory frameworks presents substantial pedagogical challenges for educators attempting to convey abstract concepts to tenth-grade students who lack direct experience with financial regulatory systems. Traditional lecture-based approaches have demonstrated limited effectiveness in promoting deep understanding of OJK functions, authority, and responsibilities, necessitating innovative instructional strategies that can bridge the gap between theoretical knowledge and practical comprehension.

The effectiveness of AR-integrated educational materials has been particularly demonstrated in Indonesian contexts. There are research and development studies that show that AR-integrated e-books are effective in improving critical thinking skills and multi-representational abilities (Rahmayani et al., 2024). Their findings revealed that AR e-book usage is more effective and positively impacts student learning in physics, particularly in renewable energy subjects, suggesting significant potential for AR applications across various educational domains within Indonesian educational settings.

The widespread adoption of smartphone technology among Indonesian adolescents, with Android devices representing the dominant platform, creates an unprecedented opportunity for mobile-based educational innovation (We Are Social Meltwater, 2023). This technological accessibility, combined with advancing AR capabilities through platforms such as ARCore, enables the development of sophisticated educational applications that can transform abstract regulatory concepts into tangible, interactive learning experiences. The convergence of educational need, technological capability, and student readiness creates an optimal environment for implementing AR-based solutions in financial literacy education.

This research is fundamentally grounded in constructivist learning theory, which emphasizes active knowledge construction through direct experience and interaction with educational content (Piaget, 1977; Vygotsky, 1978). The interactive nature of AR technology aligns perfectly with constructivist principles by enabling students to manipulate and explore three-dimensional representations of complex institutional structures, facilitating deeper understanding through hands-on engagement rather than passive reception of information. Vygotsky's social constructivist perspective further supports AR implementation by emphasizing collaborative learning opportunities that can emerge from shared AR experiences (Vygotsky, 1978). The ability to collectively explore and discuss AR-enhanced content creates opportunities for peer learning and knowledge sharing that enhance individual understanding while building collective knowledge within classroom communities.

Mayer's Cognitive Theory of Multimedia Learning provides critical theoretical justification for AR-based educational applications by demonstrating how information presented through multiple sensory channels optimizes learning effectiveness (Mayer, 2021). AR technology's unique ability to combine visual, auditory, and kinesthetic elements creates rich multimedia experiences that can significantly reduce cognitive load while enhancing information processing and retention capabilities. Dual coding theory further supports AR educational applications by suggesting that information processed through both visual and verbal channels results in enhanced memory formation (J. Clark & Paivio, 1987). AR implementations that seamlessly integrate 3D visualizations with video content and interactive elements can leverage these cognitive processing advantages to create superior learning experiences compared to traditional instructional approaches.

The Technology Acceptance Model (TAM) developed by Davis (1989), provides an important theoretical framework for understanding the factors that influence students' adoption of AR-based learning technologies (Ma & Liu, 2005). TAM identifies perceived usefulness and perceived ease of use as primary determinants of technology acceptance, making these constructs critical considerations in AR educational application development and implementation. Extended TAM models incorporating social influence, facilitating conditions, and individual differences provide additional insights into technology adoption patterns that can inform successful AR implementation strategies (Venkatesh et al., 2003). Understanding these theoretical relationships enables the development

of AR applications that maximize both functional effectiveness and user acceptance among target student populations.

Recent meta-analytical research has consistently demonstrated positive effects of AR technology on student learning outcomes across diverse educational contexts (Akçayır & Akçayır, 2017; Garzón, 2019). Studies examining AR implementation in secondary education have reported significant improvements in student motivation, conceptual understanding, and learning satisfaction, with effect sizes typically ranging from moderate to large compared to traditional instructional approaches (Bacca-Acosta et al., 2014; Chen, L., Chen, P. and Lin, 2020). However, existing AR educational research has predominantly focused on STEM subjects, with limited investigation of applications in social science and economics education contexts (Bower et al., 2014). This research gap is particularly significant given the unique challenges of teaching abstract institutional and regulatory concepts that characterize financial literacy education.

International research consistently identifies significant challenges in financial literacy education, particularly regarding the teaching of complex institutional frameworks and regulatory concepts (Huston, 2010; Mandell & Klein, 2009). Traditional approaches to financial education have demonstrated limited long-term effectiveness, with knowledge gains often failing to translate into improved financial behaviors and decision-making capabilities (Fernandes et al., 2014). The specific challenges of teaching regulatory institutions such as financial services authorities have received minimal research attention, despite their critical importance in comprehensive financial literacy development. Understanding complex institutional roles, functions, and authority requires sophisticated cognitive processing that may be significantly enhanced through interactive and immersive learning experiences.

Indonesia's National Financial Literacy Strategy emphasizes the integration of innovative educational approaches to achieve national financial inclusion objectives (Bank Indonesia, 2021). Current financial literacy rates among Indonesian secondary students remain below target levels, indicating the need for more effective educational strategies that can enhance both knowledge acquisition and practical application capabilities. Research within Indonesian educational contexts has identified high mobile technology adoption rates among student populations, creating favorable conditions for mobile-based educational innovations (Margaretha & Pambudhi, 2015). However, the gap between technology availability and educational utilization remains substantial, representing a significant opportunity for innovative applications such as AR-based learning materials. This study focuses specifically on developing and validating an AR-based learning prototype for OJK education among 40 Indonesian tenth-grade students enrolled in economics courses in West Java Province. The research encompasses comprehensive needs assessment, prototype application development targeting Unity 3D and ARCore platforms, and expert validation by qualified content and design specialists.

Research Objectives

The primary objective of this research is to develop and validate a prototype AR-based learning application for Financial Services Authority (OJK)

education that can effectively enhance student engagement and learning outcomes among Indonesian tenth-grade students through systematic needs assessment, prototype development, and expert validation. This study addresses the identified research gap by investigating AR applications in financial literacy education while contributing to the growing body of evidence supporting technology-enhanced learning approaches in Indonesian educational contexts, while acknowledging the inherent challenges in AR implementation for educational purposes.

This research focuses specifically on developing and validating an AR-based learning prototype for OJK education among Indonesian tenth-grade students enrolled in economics courses. The study encompasses comprehensive needs assessment (n=40), prototype application development targeting Unity 3D and ARCore platforms, and expert validation by qualified content and design specialists. The research addresses four main OJK content areas integrated within the AR application: organizational structure and functions, regulatory authority and powers, supervisory responsibilities, and consumer protection mechanisms. Technical development focuses on Android-based AR prototype implementation due to platform prevalence and accessibility within Indonesian educational contexts, while recognizing the technical complexities inherent in AR educational application development.

Several limitations must be acknowledged in this research. First, the sample of 40 students from West Java Province limits generalizability to broader Indonesian populations and international contexts. While providing valuable insights into AR-based financial literacy education, the geographic specificity constrains applicability across diverse socioeconomic and cultural settings. Second, the Android-focused AR development restricts broader platform applicability. Although justified by Android's market dominance in Indonesia, iOS exclusion limits accessibility for Apple device users, constraining the intervention's comprehensive reach. Third, the evaluation framework emphasizes initial technology acceptance and expert validation rather than longitudinal learning assessment or full-scale implementation testing. While immediate acceptance metrics validate the AR system's educational potential, the absence of long-term follow-up studies limits understanding of sustained learning effects, knowledge retention, and behavioral change durability in financial decision-making. Fourth, the prototype nature of the AR implementation presents technical challenges that may affect functionality and user experience, requiring acknowledgment that this represents initial development rather than a fully-realized educational solution. Finally, content specificity focusing on OJK regulatory concepts may constrain direct transferability to other financial education contexts or international regulatory environments. However, the underlying methodological framework, AR prototype development strategies, and pedagogical approaches remain sufficiently robust for adaptation to diverse financial literacy topics beyond Indonesian financial regulations, while the lessons learned from implementation challenges provide valuable insights for future AR educational initiatives.

METHODS

This study employed a mixed-methods research and development (R&D) approach based on the ADDIE (Branch, 2010). The research design integrated quantitative survey methods for needs assessment and expert validation with qualitative analysis of educational content and user experience feedback. The study was conducted between March 2024 and December 2024, following ethical approval from the institutional review board. The research was conducted in collaboration with senior high schools in West Java Province, Indonesia, focusing on tenth-grade students studying economics and financial literacy curricula. The selection of this educational level was based on the Indonesian national curriculum structure, where Financial Services Authority (OJK) concepts are first introduced as part of economic education requirements.

The Content Validity Index (CVI) calculation yielded a score of 0.875, which exceeds the minimum threshold of 0.78 recommended for educational materials (Polit & Beck, 2006). The Design Quality Index (DQI) reached 0.778, meeting the acceptable threshold for multimedia learning materials (Nielsen, 2012). The study employed purposive sampling methodology to select participants based on predetermined criteria that were directly aligned with the research objectives (Magnone & Yezierski, 2024). This non-probability sampling approach ensured that all selected participants met the specific requirements necessary for meaningful participation in the study. The inclusion criteria for student participants were carefully established to maintain consistency and relevance to the research goals. Participants were required to be enrolled in tenth grade, representing their first year of senior high school education. Additionally, all participants needed to be currently studying economics as part of their curriculum, with particular emphasis on those whose coursework included financial literacy components. Technical accessibility was ensured by requiring participants to have access to Android-compatible smartphones, which was essential for the augmented reality application functionality. Finally, ethical considerations were prioritized through the requirement of voluntary participation, with all participants providing informed consent before joining the study. This systematic selection process resulted in a homogeneous sample that could effectively evaluate the educational intervention while maintaining the validity and reliability of the research findings.

The study participants consisted of 40 high school students with a gender distribution of 22 females (55%) and 18 males (45%). The age range of participants was between 15-16 years, with a mean age of 15.6 years and a standard deviation of 0.5. All participants (100%) were daily smartphone users, demonstrating high familiarity with mobile technology. Regarding prior experience with augmented reality (AR), only 30% of participants had previous exposure, which was limited to gaming applications. This demographic profile indicates a tech-savvy student population with minimal formal AR experience, making them ideal candidates for evaluating educational AR applications.

The data collection technique in this study used a Needs Assessment Survey. A comprehensive survey was conducted via Google Forms to assess: (1) Learning motivation and current media preferences; (2) Technology acceptance

using the TAM construct (perceived usefulness and ease of use); (3) Student acceptance of AR-based learning materials; and (4) Demographic patterns and technology use. Next, an expert validation instrument was developed using two structured evaluation rubrics, namely the Content Validation Rubric and the Design Validation Rubric. This content validation rubric assesses eight criteria, including: (1) Accuracy and relevance of content; (2) Completeness of material; (3) Logical sequence and flow; (4) Quality of presentation; (5) Clarity and appropriateness of language; (6) Age-appropriate content level; (7) Alignment with curriculum standards; and (8) Potential for achieving learning objectives. Meanwhile, the design validation rubric evaluates nine dimensions, including: (1) Consistency of visual design; (2) Clarity and quality of multimedia; (3) Usability of user interface; (4) Typography and readability; (5) Quality and relevance of animation; (6) Appropriateness of color scheme; (7) Intuitiveness of navigation; (8) Integration of AR functionality; and (9) Overall aesthetic appeal.

The AR application was developed using the Unity 3D engine and ARCore SDK, targeting Android devices. This application integrates four main OJK content modules, namely; (1) Organizational structure and functions; (2) Regulatory authority and powers; (3) Supervisory responsibilities; and (4) Consumer protection mechanisms. Then the quantitative data analysis techniques used include: (1) Descriptive statistics for demographic characteristics and survey responses; (2) Correlation analysis to test the relationship between variables; (3) Chi-square test for categorical associations; and (4) Calculation of the Content Validity Index (CVI) and Design Quality Index (DQI). Qualitative data from expert feedback was analyzed using thematic analysis to identify patterns and recommendations for improvement.

Expert validation employed purposive sampling to select two qualified specialists: one content expert in economic education from Universitas Swadaya Gunung Jati with minimum 10 years experience in financial literacy curriculum development, and one multimedia learning design specialist with proven expertise in AR educational applications. This dual-expert approach ensures comprehensive evaluation from both pedagogical and technical perspectives.

RESULTS & DISCUSSION

Result

The preliminary needs assessment conducted among 40 tenth-grade high school students revealed significant insights into current pedagogical challenges and technological readiness in financial literacy education. The comprehensive survey, administered through Google Forms using purposive sampling methodology, generated quantitative data that informed the subsequent development phases. The ADDIE framework implementation in this study focused primarily on Analysis, Design, Development, and Evaluation phases, with the Implementation phase remaining beyond the current research scope. This methodological limitation restricts conclusions about full-scale classroom deployment effectiveness and long-term educational impact assessment. The

purposive sampling methodology, while ensuring participant relevance to research objectives, may limit random generalizability to broader student populations.

Student Learning Motivation and Media Preferences

The analysis of student responses regarding learning motivation and media utilization demonstrated a strong correlation between media diversification and academic engagement, providing empirical support for multimedia learning theories. Out of 40 respondents, 25 students (62.5%) reported enhanced learning motivation when exposed to varied instructional media formats, indicating a substantial preference for multimodal learning approaches over traditional single-medium instruction. This finding aligns with contemporary educational research emphasizing the critical role of multimedia approaches in student engagement (R. Clark et al., 2016; Mayer, 2021), and corroborates previous studies that have documented the motivational benefits of technology-enhanced learning environments.

Statistical analysis revealed a significant positive correlation ($r = 0.734$, $p < 0.01$) between media variety and self-reported learning interest, suggesting that traditional pedagogical approaches may be insufficient for contemporary digital-native learners who have grown accustomed to rich, interactive media experiences. The strength of this correlation indicates that approximately 54% of the variance in learning motivation can be attributed to media diversification strategies, representing a substantial effect size according to Cohen's (1988) guidelines for correlation interpretation. The chi-square test ($\chi^2 = 8.92$, $df = 1$, $p < 0.05$) confirmed the statistical significance of this relationship, indicating that media diversification strategies could substantially impact learning outcomes and warranting further investigation into optimal media combination approaches.

These findings provide empirical validation for Mayer's Cognitive Theory of Multimedia Learning, which posits that learning is enhanced when information is presented through multiple sensory channels, allowing for more effective cognitive processing and knowledge retention (Mayer, 2021). The observed correlation between media variety and student motivation also supports (Mehiri, 2020). Multiple Intelligence Theory, suggesting that diverse media formats can accommodate different learning preferences and cognitive strengths. Furthermore, the results align with constructivist learning principles, where varied media formats enable students to construct knowledge through multiple pathways and representations, facilitating deeper understanding and engagement with the subject matter.

The practical implications of these findings extend beyond theoretical validation, offering concrete evidence for educational practitioners and policymakers regarding the necessity of incorporating multimedia approaches in contemporary curriculum design. The 62.5% positive response rate suggests that a significant majority of students benefit from diversified instructional media, while the remaining 37.5% may require alternative engagement strategies or different combinations of media formats. This heterogeneity in student responses underscores the importance of adaptive learning approaches that can accommodate diverse learning preferences and technological comfort levels. The statistical significance of the relationship between media diversification and

learning motivation provides a compelling argument for educational institutions to invest in multimedia learning infrastructure and professional development programs that enable educators to effectively integrate various media formats into their instructional practices.

Student Receptivity to AR-Based Learning Materials

The assessment of existing Augmented Reality implementation in educational contexts revealed a substantial technology gap. Among the surveyed population, 65% of educators (26 out of 40) had not incorporated AR-based media into their instructional practices. This finding indicates a significant opportunity for technological innovation in financial literacy education, particularly given the increasing availability of AR-enabled devices and platforms. The technology readiness assessment employed the Technology Acceptance Model (TAM) framework, revealing that while perceived usefulness scored high ($M = 4.2$, $SD = 0.8$), perceived ease of use remained moderate ($M = 3.1$, $SD = 0.9$). This disparity suggests that successful AR implementation requires comprehensive training and support systems for educators. Student responses to the proposed AR-based learning module development demonstrated strong support, with 27 out of 40 respondents (67.5%) expressing positive attitudes toward AR integration. This receptivity rate significantly exceeded the threshold typically required for successful educational technology (Zawacki-Richter & Jung, 2023; Elbadiansyah et al., 2024; Granić, 2022; Venkatesh, 2014). Demographic analysis revealed interesting patterns in AR acceptance. Students with higher frequency of smartphone usage (>6 hours daily) showed significantly greater AR acceptance rates ($t = 3.24$, $p < 0.01$), suggesting that digital familiarity positively influences technology adoption in educational contexts.

Expert Validation Results

The expert validation process employed two qualified specialists to ensure comprehensive evaluation from both pedagogical and technical perspectives. The content validation was conducted by a recognized expert in economic education from Universitas Swadaya Gunung Jati, while design validation was performed by a multimedia learning design specialist. This dual-expert approach, while limited in scope, provided focused and detailed feedback on both educational content quality and technical implementation aspects.

The content validation process revealed varying levels of effectiveness across the four main OJK content areas integrated within the AR application. The organizational structure and functions component achieved the highest validation score of 90%, with the content expert commending the excellent three-dimensional representation of OJK's hierarchical structure and the clear explanation of departmental roles through interactive AR models. This high score reflects the application's success in transforming abstract institutional frameworks into tangible, explorable digital environments that enable students to navigate and understand complex organizational relationships. The following table presents the content validation results in detail.

Table 1. Content Validation Results Based on OJK Content Areas

Content Area	Validation Score	Expert Assessment
Organizational structure and functions	90%	Excellent 3D representation of hierarchical structure
Regulatory authority and powers	85%	Comprehensive coverage with minor enhancement needs
Supervisory responsibilities	85%	Effective AR simulations of oversight functions
Consumer protection mechanisms	90%	Outstanding relevance to student experiences
Overall Content Validity	**87.5%**	**CVI = 0.875**

A detailed assessment based on the content validation criteria is presented below.

Table 2. Content Validation Criteria Assessment

Validation Criteria	Score	Comments
Content accuracy and relevance	100%	Fully aligned with OJK regulatory framework
Material completeness	80%	Comprehensive with minor gaps identified
Logical sequence and flow	100%	Excellent progression of concepts
Presentation quality	80%	High quality with room for enhancement
Language clarity and appropriateness	80%	Generally clear, some technical terms need simplification
Age-appropriate content level	80%	Suitable for tenth-grade comprehension
Alignment with curriculum standards	80%	Good integration with economics curriculum
Learning objective achievement potential	100%	Strong potential for meeting educational goals

The Content Validity Index (CVI) calculation yielded a score of 0.875, which exceeds the minimum threshold of 0.78 recommended for educational materials (Polit & Beck, 2006). Content experts provided qualitative feedback emphasizing the material's strong theoretical foundation and practical application, particularly emphasizing the innovative approach to realizing abstract regulatory concepts through AR visualization.

Both regulatory authority and powers, and supervisory responsibilities components received identical scores of 85%, indicating strong educational value with identified areas for improvement. The regulatory authority and powers section demonstrated comprehensive coverage of regulatory mechanisms through AR-enhanced case studies and interactive regulatory process flows. However, the content expert noted that some complex legal concepts embedded within regulatory frameworks require additional explanatory support to ensure tenth-grade comprehension levels. Similarly, the supervisory responsibilities component effectively demonstrated oversight functions through AR simulations of regulatory scenarios, with particularly strong integration of real-world case studies that contextualize abstract supervisory concepts within familiar Indonesian financial contexts.

The consumer protection mechanisms component achieved an outstanding score of 90%, reflecting the application's exceptional success in presenting consumer rights and complaint procedures through interactive AR scenarios. The content expert specifically highlighted the high relevance of this component to student experiences, noting that the AR application effectively bridges the gap between theoretical consumer protection concepts and practical applications that students may encounter in their daily financial interactions. This component's success demonstrates the particular strength of AR technology in making regulatory concepts personally relevant and immediately applicable to student experiences, supporting the theoretical framework of experiential learning within financial literacy education.

Table 3. Validation Criteria

Overall content validity score	87,5%
Content accuracy and relevance	100%
Material completeness	80%
Logical sequence and flow	100%
Presentation quality	80%
Language clarity and appropriateness	80%
Age-appropriate content level	80%
Alignment with curriculum standards	80%
Learning objective achievement potential	100%

The content expert provided detailed qualitative feedback emphasizing the material's strong theoretical foundation and practical applicability, particularly noting the innovative approach to making abstract regulatory concepts tangible through AR visualization. Specific commendations included the comprehensive coverage of OJK functions across all four content areas, clear explanation of regulatory mechanisms through interactive 3D models, and appropriate integration of real-world Indonesian financial cases.

Minor recommendations focused on enhancing visual-textual balance within the AR interface, incorporating additional case studies from diverse Indonesian financial contexts, and providing more detailed explanations for complex regulatory terminology that may challenge tenth-grade comprehension levels.

Design Validation - Technical Implementation Challenges

The multimedia learning design evaluation was conducted by a design specialist and assessed nine critical design dimensions. The results are presented in the following table.

Table 4. Design Validation Assessment Results

Design Dimension	Score	Assessment Details
Visual design consistency	100%	Excellent coherence across interface elements
Multimedia clarity and quality	80%	High-quality content with minor optimization needs
User interface usability	80%	Intuitive navigation with improvement opportunities

Design Dimension	Score	Assessment Details
Typography and readability	60%	Adequate but requires enhancement for optimal legibility
Animation quality and relevance	80%	Effective educational animations
Color scheme appropriateness	100%	Excellent visual appeal and accessibility compliance
Navigation intuitiveness	80%	Generally user-friendly with minor adjustments needed
AR functionality integration	20%	Significant technical limitations identified
Overall aesthetic appeal	100%	Outstanding visual design quality
Overall Design Validity	**77.8%**	**DQI = 0.778**

The Design Quality Index (DQI) reached 0.778, meeting the acceptable threshold for multimedia learning materials (Nielsen, 2012). The integration of AR functionality exhibited significant limitations, achieving only 20% effectiveness due to various interrelated challenges, namely: (1) ARCore Implementation: Tracking inconsistencies in varying lighting conditions; (2) Performance Issues: Frame rate drops on mid-range Android devices; (3) Interface Scalability: AR elements failed to maintain proportions across different screen sizes; (4) Content Synchronization: Temporal misalignment between 3D content and multimedia elements; (5) Device Compatibility: Performance disparities across different Android specifications. These technical limitations reflect the complexity of implementing educational AR applications in environments with limited resources and varying hardware specifications commonly found in educational settings in Indonesia. Then the multimedia learning design evaluates nine critical design dimensions which can be seen in the table below.

Table 5. Validation Design

Overall design validity score	77.8%
Visual design consistency	100%
Multimedia clarity and quality	80%
User interface usability	80%
Typography and readability	60%
Animation quality and relevance	80%
Color scheme appropriateness	100%
Navigation intuitiveness	80%
AR functionality integration	20%
Overall aesthetic appeal	100%

The AR functionality integration demonstrated significant technical limitations, achieving a critically low implementation score of 20%. This substantial underperformance can be attributed to multiple interconnected technical challenges that emerged during the prototype development phase. The ARCore implementation exhibited considerable instability in marker tracking capabilities, particularly when deployed in varying lighting conditions commonly encountered in Indonesian educational environments. Performance bottlenecks

were consistently observed when rendering complex three-dimensional models representing OJK organizational charts and regulatory flowcharts, with mid-range Android devices—which constitute the majority of the target user demographic—experiencing significant frame rate drops and rendering delays. User interface scalability presented additional complications, as AR text elements and interactive components failed to maintain appropriate proportions across different screen dimensions and optimal viewing distances, thereby compromising user experience and content accessibility. Furthermore, the synchronization between three-dimensional AR content and accompanying multimedia elements, including audio narration and textual explanations, proved technically challenging, resulting in temporal misalignment that disrupted the intended educational flow. The limited scope of device compatibility testing revealed substantial performance disparities across diverse Android hardware specifications, with older devices experiencing frequent application crashes and rendering failures, ultimately limiting the solution's practical deployment potential in resource-constrained educational settings.

Discussion

Challenges in AR Educational Prototype Development

The integration of augmented reality (AR) technology in educational contexts has demonstrated significant potential for enhancing student engagement and learning outcomes across various disciplines. Previous studies have consistently shown positive impacts on learner motivation and performance, finding that students engage effectively in self-directed learning outside of class using mobile devices, demonstrating a successful adaptation of technology-enhanced traditional methods (Lo et al., 2021). The adaptability of this technology is supported by a study reporting positive emotional effects of AR on learner motivation (Mystakidis, 2022). While other studies have shown that AR increases motivation compared to conventional materials (Ivarson et al., 2024). The educational effectiveness of AR implementation has been empirically validated through a comparative study which found that, AR-based student groups outperformed traditional teaching-based learning groups in both learning outcomes and attitudes (Wu et al., 2022). Further other research established that, AR tools effectively engage and motivate collaborative team knowledge building, highlighting the technology's capacity to facilitate social learning processes (Lu et al., 2022).

However, the empirical findings from this investigation reveal critical insights into the practical complexities of AR educational application development that extend substantially beyond these theoretical conceptualization frameworks, particularly illuminating the pronounced disconnect between pedagogical design potential and technological implementation feasibility within resource-constrained educational environments. The substantial performance gap between design validation outcomes, demonstrated through exceptional scores in visual design elements achieving perfect ratings (100%), and AR functionality implementation achieving merely 20% effectiveness, illustrates the multifaceted technical challenges inherent in successfully translating well-conceived

educational frameworks into functionally robust AR experiences that simultaneously satisfy rigorous pedagogical objectives and demanding technical performance standards (Nielsen, 2012; Bower et al., 2014). This empirical disparity underscores a fundamental research contribution that successful educational content validation and superior interface design do not necessarily predict successful technical implementation, thereby revealing previously underexplored distinctions between conventional educational material development methodologies and AR-based educational technology creation processes that require fundamentally different development paradigms and technical competencies.

The critically deficient AR functionality performance reflects multiple interconnected systemic factors that collectively constrain educational AR development effectiveness within authentic implementation contexts, extending beyond isolated technical considerations to encompass broader socio-technical challenges. Technical infrastructure limitations emerge as the predominant constraining factor, wherein the substantial heterogeneity of Android device specifications utilized by Indonesian secondary students presents formidable optimization challenges that significantly exceed those encountered within controlled laboratory development environments or homogeneous device ecosystems typical of developed educational contexts (We Are Social Meltwater, 2023). Real-world classroom implementation environments involve highly variable hardware architectures, diverse screen dimensions and resolutions, inconsistent processing capabilities, and fluctuating network connectivity conditions that collectively compromise AR application consistency and sustainable user experience delivery, thereby necessitating sophisticated adaptive programming architectures and dynamic resource allocation strategies not conventionally required in traditional educational software development paradigms.

Furthermore, the pedagogical complexity inherent in translating multidimensional OJK regulatory content areas into seamless, educationally effective AR interactions revealed substantial challenges in advanced visualization technique implementation, as abstract financial regulatory concepts necessitate sophisticated three-dimensional spatial representations, dynamic interactive elements, and real-time data processing capabilities that approach or exceed the technical boundaries of contemporary mobile AR development frameworks, particularly when targeting educational applications that demand conceptual accuracy, comprehensive content coverage, and sustained cognitive engagement rather than the simplified, entertainment-focused presentations characteristic of commercial AR implementations (Akçayır & Akçayır, 2017; Garzón, 2019).

Theoretical Validation Despite Technical Challenges

Despite technical implementation challenges, this study successfully validated the main theoretical framework established in previous AR education research. The high student acceptance rate (67.5%) is in line with the positive outcomes (Mystakidis, 2022; Ivarson et al., 2024). Meanwhile, the positive correlation between media diversification and learning motivation ($r = 0.734$, $p <$

0.01) provides empirical support for the predictions of the Technology Acceptance Model and the principles of Multimedia Learning Theory (Wu et al., 2022; Lu et al., 2022).

The content validation success (87.5%) across all four OJK content areas demonstrates that complex financial regulatory concepts can be effectively adapted for AR-based learning experiences, even when technical implementation remains challenging. This finding suggests that the pedagogical framework developed in this research remains valuable for future AR educational initiatives, even as technical solutions continue to evolve, supporting the theoretical foundations established by previous research while highlighting the implementation gap between theory and practice in resource-constrained environments.

Bridging Theory and Practice in AR Educational Development

This research additionally identifies theoretically significant distinctions between educational and entertainment-oriented AR applications that introduce unique technical constraints and development challenges rarely encountered in conventional AR application domains, contributing novel insights to the growing body of educational technology literature. While gaming, marketing, or consumer-oriented AR applications can strategically prioritize immediate visual impact, brief user engagement episodes, and simplified interaction patterns designed for momentary attention capture, educational AR applications must facilitate sustained cognitive interaction, maintain hierarchically structured information architectures, support complex knowledge construction processes, and deliver consistent technical performance throughout extended learning sessions that frequently span complete instructional periods of 45-90 minutes duration (Mayer, 2021; Vygotsky, 1978). These educationally-specific functional requirements demand exceptionally robust technical architectures capable of maintaining optimal functionality under prolonged operational conditions while simultaneously supporting sophisticated pedagogical interactions that enable meaningful, measurable learning outcomes aligned with established educational objectives and assessment criteria.

The empirical evidence demonstrates that educational AR development constitutes a distinct technical and pedagogical challenge requiring specialized methodological approaches that systematically account for both educational effectiveness criteria and sustained technical performance requirements, thereby suggesting that successful educational AR implementation necessitates development methodologies, validation frameworks, and deployment strategies specifically adapted to educational contexts rather than direct adaptation of commercial application development approaches. This finding contributes significantly to Technology Acceptance Model literature by identifying context-specific factors that influence educational technology adoption beyond traditional perceived usefulness and ease of use constructs, while simultaneously advancing Constructivist Learning Theory applications by demonstrating the complex interplay between technological capabilities and pedagogical effectiveness in immersive learning environments (Granić, 2022).

Implications for Future AR Educational Development

This research contributes valuable insights into establishing realistic expectations for AR educational prototype development, particularly highlighting the critical gap between educational design success and technical implementation feasibility demonstrated in previous optimistic studies. While several studies have established the theoretical and motivational benefits of AR in education, findings suggest that successful AR educational initiatives require a fundamentally different development approach than traditional educational content creation, requiring iterative development methodologies that accommodate extensive testing and refinement cycles that extend beyond conventional educational content development timelines (Cruz-Loera et al., 2024; Dhaas, 2024; Garzón, 2021; Marin-Rodriguez et al., 2023). These extended development periods reflect the inherent complexity of translating pedagogical concepts into functional AR experiences while maintaining educational effectiveness and technical stability across diverse hardware environments.

The research findings strongly emphasize the necessity for comprehensive technical-pedagogical integration throughout the development process, moving beyond traditional models where technical implementation follows educational design completion. Successful AR educational applications require sustained collaboration between educational content experts and AR technical specialists from initial conceptualization through final implementation, ensuring that pedagogical objectives remain achievable within technical constraints while leveraging AR capabilities to enhance rather than complicate learning experiences. This integrated approach addresses the disconnect observed between high educational content validation scores and low technical functionality scores, suggesting that siloed development approaches significantly compromise final application effectiveness.

Furthermore, the study reveals critical considerations regarding hardware limitations that must inform AR educational application design decisions, particularly within developing country contexts characterized by high device diversity and varying performance capabilities. The research demonstrates that educational AR applications cannot assume uniform hardware specifications or optimal viewing conditions, requiring design strategies that accommodate mid-range Android devices, variable lighting conditions, and diverse screen sizes commonly encountered in Indonesian educational environments. Consequently, the findings support implementing phased deployment strategies that introduce AR elements gradually as technical capabilities improve and hardware standardization increases, rather than pursuing immediate full-functionality implementations that may compromise user experience and educational effectiveness. This phased approach enables educational institutions to realize immediate benefits from AR integration while building technical capacity and infrastructure to support more sophisticated implementations over time, ultimately ensuring sustainable adoption and long-term educational impact within resource-constrained environments.

Limitations and Future Research Directions

The research employed a relatively small sample size (n=40) from a single educational context, potentially limiting the generalizability of findings to broader populations. The prototype nature of the AR implementation, while providing valuable insights into development challenges, limits conclusions about full-scale educational effectiveness. Future research should incorporate larger, more diverse samples across multiple institutions and geographic regions to enhance external validity and build upon the foundational work established (Khairiyah et al., 2024). Current studies focus on initial acceptance and expert validation, rather than longitudinal learning outcomes or ongoing technical performance assessments. Future research should investigate the long-term impact of AR-based learning materials on students' achievement, retention, and practical application of financial literacy, while also addressing technical optimizations for different device environments. This longitudinal approach would complement the reported motivational findings with comprehensive learning outcome data (Chang et al., 2022; Hunaepi et al., 2023).

Controlled experimental studies comparing refined AR-based learning outcomes with traditional instructional approaches would provide valuable evidence regarding the technology's educational effectiveness and cost-benefit ratio once technical implementation challenges are resolved. The expert validation methodology employed in this research provides a replicable framework for ensuring AR educational material quality, though future studies should expand expert panels to include technical AR specialists alongside educational content experts. The technical challenges identified in this research provide important guidance for future AR educational development initiatives, suggesting that realistic timelines and resource allocation must account for iterative technical refinement processes that extend beyond traditional educational material development cycles. These findings complement the optimistic results reported in previous studies by providing a realistic assessment of the implementation challenges that must be addressed to achieve the educational benefits demonstrated in controlled environments (Familoni & Onyebuchi, 2024).

CONCLUSION

This research successfully demonstrates the feasibility and potential effectiveness of Augmented Reality-based learning materials for Financial Services Authority (OJK) education among Indonesian high school students. The high student acceptance rate (67.5%) and positive expert validation results (content: 87.5%, design: 77.8%) provide strong evidence supporting AR technology integration in financial literacy education. The study contributes to educational technology theory by providing empirical evidence for constructivist learning principles and multimedia learning theory application in financial education contexts. Practically, the research offers a replicable framework for developing high-quality AR educational materials and highlights critical considerations for successful implementation. While technical challenges remain, particularly in AR functionality integration, the research establishes a foundation

for future development and broader implementation of innovative educational technologies in Indonesian secondary education. The findings support continued investment in educational technology innovation as a means of enhancing financial literacy education quality and accessibility. Future research should focus on longitudinal impact assessment, comparative effectiveness studies, and broader implementation across diverse educational contexts to further validate and refine the proposed AR-based learning approach.

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