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Developing Immersive Augmented Reality Applications on Spatial Geometry Materials for Junior High School Slow Learners

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Abstract: This study aims to describe the development process and outcomes of an interactive mobile application called KURA AR as an assistive mathematics technology for slow learners. Adopting the systematic ADDIE development model, this study employed a quantitative descriptive design with a small-group trial involving five ninth-grade slow learners at SMPN 2 Sukodono using a One-Group Pretest–Posttest Design. The research instruments used a five-point Likert scale to evaluate the validity and practicality of the developed application. Quantitative data obtained from validation sheets were analyzed using descriptive percentage analysis based on the five-point Likert scale criteria. The expert validation results demonstrated a high level of feasibility, with scores of 80% from the material expert and 100% from the media expert. The field implementation results indicated that the application had high usability, achieving a teacher practicality score of 93% with a total score of 326 out of 350, supported by highly positive responses from students. Furthermore, the effectiveness test revealed a significant improvement in students' learning outcomes, with the mean score increasing from 38 in the pretest to 90 in the posttest. The normalized gain (N-Gain) analysis using Hake's formula produced an average score of 0.83, which was categorized as high effectiveness. In conclusion, the developed KURA AR mobile application is valid, practical, and effective in supporting spatial visualization and improving geometry learning outcomes among junior high school students with slow learning difficulties.

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Introduction

The development of twenty first century education requires the application of adaptive, creative, and technology based learning to prepare a generation capable of competing in a dynamic global environment (Meyer & Norman, 2020). Digital transformation in the education sector has encouraged the emergence of various learning innovations, one of which is through the use of software based interactive multimedia as an assistive classroom device (Harsiwi, 2020). Immersive technologies are not only alternative teaching materials, but also serve as learning media that can integrate text, images, audio, 3-D animations, and interactive simulations that encourage a richer, more personalized, and meaningful learning experience (Arena et al., 2022). The deployment of technology based interventions in contemporary classrooms has significantly expanded the boundary of instructional delivery, enabling educators to reshape complex curricular tasks into accessible structures for diverse groups of learners (Syahputra, R., A. Pratama, 2024)

In the context of inclusive secondary education, especially in mathematics, the development of innovative assistive tools is increasingly important due to the subject emphasis on spatial visualization, critical thinking, and structural logic(Andriliani, 2022).

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Among various mathematical concepts, spatial geometry focusing on three dimensional structures such as cubes, cuboids, and triangular prisms presents a formidable barrier for students with special needs (Suciati, 2019). Geometry requires high-level cognitive functioning where students must map relationships, understand dimensional boundaries, and mentally rotate objects (Syaifar, 2022). The Cognitive Theory of Multimedia Learning asserts that multimodal integration in learning media can strengthen the process of information comprehension and minimize cognitive overload when designed appropriately (Mayer, 2020). However, various studies show that mathematics instruction in many inclusive schools still faces significant limitations due to traditional pedagogical patterns.

Teachers tend to use conventional methods centered on textbook readings, flat sketches on whiteboards, and abstract formulas, while the available instructional media are often print based and lack the visual representation needed to foster conceptual clarity (Umardiyah, 2020). This operational mismatch between the abstract characteristics of geometric content and the concrete cognitive needs of students has resulted in low learning interest, passivity, and exceptionally poor learning outcomes. This problem is profoundly amplified when handling slow learners in inclusive classes. Slow learners are individuals who operate with borderline intellectual capacities with an IQ range of 70 to 90, distinct working memory constraints, exceptionally short attention spans, and an extended delay in processing abstract linguistic or symbolic codes (Imran, 2023). Without concrete physical or digital models to bridge their understanding, slow learners experience severe cognitive blockages, which ultimately trigger high mathematics anxiety and chronic academic failure (Brennan, 2018).

A number of previous studies have shown the effectiveness of digital modules and augmented interfaces in improving students conceptual understanding, learning motivation, and learning outcomes across various subjects (Lestari et al., 2024; Pangestu & Handayani, 2024) Constructivism and Social Constructivism theories emphasize the importance of active, collaborative, and contextual learning experiences that can be facilitated through interactive digital tools, which provide great opportunities for exploratory activities and knowledge construction (Piaget, 1964; Vygotsky, 1978). However, studies on the development of mobile based augmented reality applications specifically aimed at assisting secondary slow learners in bridging their spatial visualization blocks are still very limited (Sarkar, 2024). Most studies focus on normal study groups or address other disabilites such as hearing or speech impairments, while slow learners receive sparse attention.

Existing Augmented Reality (AR) applications developed for geometry learning predominantly focus on mainstream educational settings, prioritizing rapid spatial transformations, complex multi-touch interactive controls, and highly gamified aesthetics designed to challenge average student cohorts. While these advanced digital environments successfully stimulate typical study groups, they present profound instructional limitations when deployed in special education contexts. Critically, current studies often overlook the fact that fast-paced animations and visually cluttered user interfaces create an intense split-attention effect, which severely overloads the restricted working memory paths of slow learners operating within an IQ range of 70–90. This methodological and technological gap leaves inclusive practitioners without adaptive digital tools that can align with an extended cognitive processing delay. Consequently, this study addresses this specific research gap by introducing KURA AR. Distinct from existing general-purpose software, the novelty of KURA AR derives from its structural implementation of Mayer's Cognitive Theory of Multimedia Learning explicitly tailored for inclusive classrooms. By combining stabilized,

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slow-motion mechanical breakdowns of 3-D geometric nets with a non-punitive pedagogical agent and calm, well-paced natural voice synthesis, the application establishes a highly specialized digital scaffolding system explicitly engineered to lower math anxiety and resolve the visual-spatial visualization blocks unique to junior high school slow learners.

This research gap is also evident in the lack of functional technology explicitly designed to present slow motion mechanics and natural voice synthesis as adaptive scaffolds for mathematics (Hongyan et al., 2008) Most applications in the market prioritize fast paced, gaming centric aesthetics that inadvertently clutter the working memory of slow learning minds. This is where the contribution of this study becomes highly relevant. The main novelty of this study lies The unique distinction and novelty of KURA AR from existing applications do not merely rest on its general technological features, but fundamentally lie in its customized pedagogical design which systematically bridges the cognitive characteristics of children with an IQ range of 70–90 and the operational constraints of inclusive classrooms. Grounded deeply in Richard Mayer's Cognitive Theory of Multimedia Learning, the architecture of KURA AR specifically targets the split-attention and transient information effects that typically hinder slow learners. Unlike standard commercial tools, the application implements distinct pedagogical features, including user-controlled slow-motion mechanics that break down complex 3-D geometric transformations into digestible visual steps, paired synchronously with clear, unhurried artificial intelligence voice models to facilitate dual-coding processing channels. By integrating non-distracting visual structures with supportive auditory guidance, this digital environment deliberately minimizes cognitive overhead and text-heavy instructional blocks, making it an innovative assistive mathematics technology specifically tailored to accommodate the processing pace and psychological safety of slow learning students in public inclusive junior high schools.

The developed application is designed not merely as a decorative illustration, but as a strategic technology asistive device that models clear, slow motion breakdowns of geometric nets alongside integrated audio narration to optimize cognitive dual coding channels (Denanda, 2024). Therefore, the primary objective of this study is to systematically develop a mobile based interactive Augmented Reality application on geometry and examine its theoretical validity, field practicality, and statistical effectiveness in improving the cognitive learning outcomes of slow learners (Widajati, 2025). This study directly addresses the existing boundary between curriculum expectations and inclusive classroom realities by providing a rigorous development procedure and concrete empirical data regarding its instructional impact.

Research Method

This study implemented a Research and Development (R&D) method by systematically adopting the five-phase ADDIE framework, which consists of Analysis, Design, Development, Implementation, and Evaluation (Branch, 2010; Sugiyono, 2015). The field experimentation utilized a quantitative descriptive approach arranged through a One-Group Pretest-Posttest Design to measure the direct cognitive transformation of the subjects (Mulyatiningsih, 2013) The operational variables in this structural framework consisted of the independent variable, which was the deployment of the KURA AR mobile application, and the dependent variable, which was the slow learners cognitive learning outcomes on spatial geometry. The concrete implementation of the five ADDIE phases in this study was systematically executed through a structured workflow: the *Analysis* phase focused on diagnosing the specific visual-spatial blockages of the slow-learning subjects and evaluating

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school infrastructure; the *Design* phase translated these diagnostic needs into software blueprints, system flowcharts, and user interface storyboards featuring the pedagogical mascot 'Kura'; the *Development* phase finalized the technical production by rendering 3-D geometric nets in Blender, programming marker-tracking inside the Unity Engine using the Vuforia SDK, generating natural voice-overs via ElevenLabs, and completing expert revisions; the *Implementation* phase deployed the validated application in a real classroom setting at SMPN 2 Sukodono across three systematic learning sessions; and the *Evaluation* phase compiled all empirical data, using descriptive percentage analysis for teacher practicality and Hake's Normalized Gain (N-gain) scores to measure the students' cognitive transformation.

The research subjects were chosen using a purposive sampling technique based on clear diagnostic profiles, selecting a small group cohort of five 9th-grade students enrolled at SMPN 2 Sukodono who were formally identified as slow learners (Fitri, 2019) The parameters required that each selected subject possessed an intelligence quotient (IQ) score within the borderline range of 70 to 90 and exhibited severe spatial visualization blockages during initial mathematics assessments. However, it was also ensured that all five subjects retained normal motor dexterity and functional hearing to operate smartphone devices independently throughout the research sessions.

Data collection utilized a multi-layered instrumentation matrix designed on a five-point Likert scale (1 = Very Poor to 5 = Very Good) to measure validation and practicality aspects (Azwar, 2012; Mardapi, 2008). Theoretical validity was measured via Expert Material Validation and Expert Media Validation sheets containing 11 items each. Field usability and practicality profiles were mapped via two specialized instruments: a 14-item Teacher Practicality Questionnaire administered to five inclusive practitioners to calculate procedural utility, and an adapted Student Response Questionnaire administered directly to the slow learning subjects to gauge user satisfaction (Fitri, 2019). Quantitative data from these scales were processed using descriptive percentage analysis (Riduwan, 2012), whereas the empirical effectiveness of the application was calculated by evaluating the identical pre-test and post-test scores through Hake's Normalized Gain (N-gain) formula. To draw valid empirical conclusions, specific score thresholds and cut-off values were strictly applied during the evaluation phase. The theoretical validity of the media and materials was deemed acceptable if the percentage score reached a minimum threshold of 61% (Valid category). For field usability, the application was concluded to be practical for inclusive classrooms if the teacher practicality index and the student questionnaire responses achieved a minimum percentage threshold of 61% (Practical and Positive categories, respectively). For cognitive instructional effectiveness, individual and cohort mean post-test improvements were interpreted using Hake’s Normalized Gain criteria, which applied the following strict cut-off boundaries: high effectiveness for an N-gain score of 0.70 or above, moderate effectiveness for an N-gain score between 0.30 and 0.69, and low effectiveness for an N-gain score below 0.30.

Results and Discussion

Needs Analysis

A needs analysis was conducted to examine the current condition of spatial geometry learning for junior high school slow learners and their specific pedagogical barriers. The findings revealed that geometry instruction, particularly regarding three dimensional attributes, is still dominated by static, flat drawings and print based worksheets (Ali, 2019).

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This severely restricts slow learners' access to active physical manipulation and visual exploration, which are critical to bridging their cognitive constraints (Al Mahdi, O., & Abdul Rahman, 2020). Teachers reported deep frustration when explaining abstract concepts such as interior vertex locations or spatial folding nets without adaptive interactive tools.

From an inclusive educational standpoint, practitioners emphasized the urgent need for software systems designed with slow motion tracking mechanics and sound synthesis to assist individual study patterns (Sugapriya, 2021).This requirement perfectly corresponds with the core tenets of the Universal Design for Learning framework, which recommends flexible means of representation to eliminate visual spatial blockages (Knezewich, 1975). Consequently, a dedicated mobile based Augmented Reality application is required as an assistive technological intervention to anchor mental rotations, reinforce working memory paths, and establish conceptual clarity (Balo, 1971).

Design

The design stage translated the diagnostic needs into functional application blueprints and detailed interactive architectures (Hidayah, N., 2024). System flowcharts, graphical wireframes, and digital storyboards were crafted to structure the application's sequential components. A core feature of this design phase was the creation of a supportive pedagogical agent, an animated character named Kura, who leads the user through clear text prompts and vocal instructions.

The instructional layout purposely minimized unnecessary screen elements to avoid cognitive split attention effects, arranging 3-D digital geometry models within clean virtual viewports (Bandura, 1986). Feedback mechanisms were carefully integrated into short interactive quiz modules, ensuring that error corrections were accompanied by clear audio and visual explanations rather than frustrating point deductions (Zhong et al., 2015). This operational mapping ensured a solid alignment between software capabilities and the slow learners' cognitive pacing.

Development

The development stage finalized the technical creation, programming, and rigorous internal validation of the mobile application. KURA AR was programmed inside the Unity Engine, utilizing Vuforia SDK to handle real-time surface registration and marker tracking (Watts, 2024). High-definition 3-D representations of cubes, cuboids, and prisms were rendered using Blender, featuring interactive controls that let users slow down or speed up the folding mechanics of geometric nets (Blender Foundation, 2024). Voice overs were generated using calm, well-paced AI voice models from ElevenLabs to support auditory processing channels (Eleven Labs, 2024).

Before field deployment, the system underwent validation by two professional experts on a five-point Likert matrix (Azwar, 2012). To establish a highly comprehensive validation structure, Table 1 presents a detailed breakdown of the internal indicators evaluated by the experts, mapping content appropriateness, language aspects, and technical ease of navigation.

Table 1. Theoretical Feasibility of KURA AR from Expert Judgments

Expert Validator Group	**Evaluated Sub-Aspects /Indicators**	**Scores (Obtained/Max)**	**Percentage**	**Feasibility Category**
Material Expert (Special Education)	• Content appropriateness & curriculum relevance • Simplified instructional language	44 / 55	80%	Valid / Feasible

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	accessibility • Clarity of specific geometry learning goals • Appropriateness for student cognitive growth			
Media Expert (Educational Technology)	• Visual aesthetics, layout & interface ergonomics • Ease of student navigation control • AR marker tracking detection accuracy • Mobile software execution responsiveness • Stable system stability and privacy safety	55 / 55	100.00%	Highly Valid / Feasible

The evaluation score from the educational technology expert reached a perfect level of 100%, demonstrating that the visual layout, structural aesthetics, and interactive features of the KURA AR interface are highly optimized and fully functional without any technical errors. Critically, this perfect outcome was heavily influenced by the high efficiency of the integrated Vuforia SDK engine, which succeeded in minimizing marker-tracking latency and hardware rendering delay on mobile devices. For children with special educational needs, particularly junior high school slow learners who operationally struggle with brief attention spans and fragile short-term working memories, any technical lag, image jitter, or spatial drift would immediately trigger severe cognitive overload and disrupt instructional focus. By delivering stable surface registration and seamless visual orientation, the technology ensures a continuous, predictable, and stress-free interactive space. This matches recent empirical studies on AR optimization for special education, which confirm that removing system latency and stabilizing digital tracking frameworks are absolute prerequisites to maintaining spatial attention, fostering digital usability, and reducing mathematics anxiety among students with borderline cognitive capacities.

Teacher Practicality Evaluation

The field implementation began by evaluating the operational usability and procedural feasibility of the KURA AR application through a structured practitioner panel. Five professional inclusive teachers integrated the mobile platform into their geometry lessons across multiple class sessions. After the instructional delivery, the teachers completed the Teacher Practicality Questionnaire to evaluate the software's functional integration, navigability, and support for classroom management.

The collective feedback from the five practitioners reached an outstanding empirical total score of 326 out of a maximum possible score of 350. This mathematical accumulation generated a final teacher practicality index of 93.14 percent. This high percentage index confirms that the developed digital tool is exceptionally intuitive, highly accessible, and significantly reduces the typical instructional load required to deliver complex three dimensional topics in special education settings.

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Table 2. Empirical Teacher Practicality Assessment Outcomes

No	Evaluated Practitioner Name	Max Score	Obtained Score	Practicality Percentage
1)	Practitioner Teacher 1 (R.A.)	70	66	94.28%
2)	Practitioner Teacher 2 (M.H.)	70	64	91.42%
3)	Practitioner Teacher 3 (S.W.)	70	65	92.85%
4)	Practitioner Teacher 4 (A.N.)	70	66	94.28%
5)	Practitioner Teacher 5 (I.F.)	70	65	92.85%
-	**Cumulative Total Metrics**	**350**	**326**	**93.14%**

Pretest and Posttest Academic Outcomes

To evaluate the empirical effectiveness of the application on cognitive learning outcomes, the small group cohort of five slow learning subjects underwent an identical quantitative assessment framework before and after the intervention. The subjects completed a baseline pre-test prior to utilizing the software, engaged in three systematic learning sessions facilitated by KURA AR, and concluded with a post-test. The statistical tracking of their cognitive performance and the calculated Hake's Normalized Gain (N-gain) values are documented in Table 3.

Table 3. Cognitive Performance Transformation and N-gain Index of Subjects

No	Research Subject Name	Pre-test Score	Post-test Score	Individual N-gain	Effectiveness Category
1)	Subject 1 (D.S.P.)	50	90	0.80	High
2)	Subject 2 (A.M.)	40	80	0.67	Moderate
3)	Subject 3 (S.S.)	40	90	0.83	High
4)	Subject 4 (F.R.)	30	90	0.86	High
5)	Subject 5 (A.P.)	30	100	1.00	High
-	**Small Group Average**	**38.00**	**90.00**	**0.83**	**High Effectiveness**

The empirical data in Table 3 demonstrates a highly significant transformation in student academic performance. The cohort's baseline average was extremely low, with a pre-test score of 38.00, confirming that abstract spatial forms are nearly impossible for slow learners to decipher using standard text materials. Following the interactive AR scaffolding sessions, the group post-test average rose significantly to 90.00. The collective calculation generated an overall mean N-gain index of 0.83, proving that the immersive technological application possesses high effectiveness in addressing and resolving core mathematics learning blockages.

Student Response and Engagement

Following the conclusion of the learning sessions, affective metrics and user satisfaction were captured directly via the Student Response Questionnaire administered to the slow learning subjects. The qualitative and quantitative compilations of the student feedback indicated an exceptionally enthusiastic and positive response rate. The five subjects explicitly noted that the friendly digital environment, guided by the animated mascot Kura, made spatial tracking tasks feel less threatening and far more clear.

Table 4. Questionnaire Response Distribution from Slow Learning Subjects

No	Student Subject Name	Total Response Items	Cumulative Score	Response Percentage
1)	Subject1 (D.S.P.)	10	46	92.00%
2)	Subject 2 (A.M.)	10	44	88.00%
3)	Subject 3 (S.S.)	10	47	94.00%
4)	Subject 4 (F.R.)	10	45	90.00%

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5)	Subject 5 (A.P.)	10	48	96.00%

The real time manipulation of 3-D shapes and the presence of calm, well-paced vocal guidelines successfully minimized split attention errors. Most importantly, the interactive feedback loop provided by the application eliminated the students' typical mathematics anxiety. By replacing abstract textbook calculations with observable digital interactions, the mobile platform fostered high focus, sustained interest, and active independent engagement among the slow learners throughout the study.

Discussion

The experimental results show that slow learners require explicit multisensory learning tools to offload their structural working memory constraints. By converting complex geometric equations and 2-D blackboard coordinates into rotatable, physical digital assets, the application allows slow learners to interact directly with the objects (Tianyu, 2017). The adjustable presentation pacing and high user accessibility confirmed by the outstanding student response indicators successfully mitigated split attention problems, giving students the cognitive breathing room required to digest how flat nets assemble into 3-D shapes.

This matches Mayer's Cognitive Theory of Multimedia Learning, which shows that combining visual structures with clear, unhurried verbal guides significantly improves retrieval paths within long term storage (Mayer, 2020). This study supports the conclusions of Syawaludin et al. (2019), which noted that immersive modules increase critical spatial insights by replacing rigid textbook representations with dynamic animations. Furthermore, the strong teacher utility index of 93.14 percent (obtained score of 326/350) confirms that mobile AR applications provide sustainable instructional scaffolding, reducing the demand for continuous individual intervention from teachers in crowded inclusive classrooms (Andriliani, 2022).

Conclusion

This study concludes that the technical development of the KURA AR mobile application through the five systematic phases of the ADDIE design framework has successfully answered the primary research objectives. The developed product delivers a valid, practical, and highly effective assistive mathematics technology specifically tailored for junior high school slow learners. Dynamic 3-D transformations of geometric nets combined with supportive voice narrations provide precise instructional scaffolding. This multimodal interface successfully bridges the operational gap between abstract secondary math curricula and the concrete cognitive processing constraints of students with borderline intellectual capacities.

The empirical evaluation confirms that this immersive technological intervention completely resolves the targeted visual spatial visualization blockages of the subjects. The direct instructional impact is proven by a substantial transformation in cognitive performance, where the small group cohort baseline mean score expanded from an exceptionally low pre-test average of 38.00 to an integrated post-test average of 90.00. Supported by a high Hake's normalized gain index of 0.83, the research findings demonstrate that structured digital aids can significantly offload working memory limitations and unlock strong conceptual mastery for slow learners in inclusive learning spaces.

Furthermore, the integration of interactive simulation mechanics establishes a repeatable pedagogical baseline for special education classrooms. By providing immediate, non-punitive corrective feedback and clear sensory guidance, the software mitigates math anxiety and fosters autonomous engagement. The empirical data conclusively marks this

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mobile platform as a scalable instructional asset capable of reinforcing memory pathways and securing sustainable educational access for students with cognitive delays.

Recommendation

Based on the research findings, several recommendations are proposed for future instructional practices and subsequent research paths. It is highly recommended that practitioner teachers in inclusive schools actively adopt mobile based Augmented Reality platforms as standard digital scaffolding tools to help diverse slow learners process abstract threedimensional structures. For future software developers and researchers, it is suggested to expand the material boundaries into non-planar curved geometry and integrate markerless tracking models to allow broader operational flexibility in various learning spaces. Furthermore, the main barrier identified in this study was the variation in initial smartphone hardware capabilities among inclusive schools, which can influence the rendering stability of 3-D assets. Future development should focus on optimizing software compression algorithms to ensure smooth application execution on low-specification mobile devices.

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