Tsaqila Jurnal Pendidikan dan Teknologi [TJPT]
Vol 6 Number 1 July 2026, hal: 49-58
ISSN: 2807-6273

Development of Augmented Reality (AR) Learning Application Integrated with Bima's Local Culture to Enhance Students' Critical Thinking Skills

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Abstract

This research aims to develop an Augmented Reality (AR) learning application integrated with Bima's local culture to enhance students' critical thinking skills in geometry lessons at SMPN 3 Woha. The main issues addressed include low digital literacy among teachers and students, as well as limited exposure to local cultural elements—such as uma lengge, sigi raja pertama, uma panggung, and asi mbojo—in mathematics education.The study tackles challenges like inadequate digital skills and the need to preserve Bima's cultural heritage through relevant educational content. The research employed a Research and Development (R&D) model using the ADDIE approach (Analysis, Design, Development, Implementation, Evaluation). It involved 40 students as subjects, with data collected via Likert-scale questionnaires, observations, interviews, and pre-post critical thinking tests. Data analysis combined qualitative and quantitative (mixed) methods. The AR application was rated highly valid (scores of 4.6-4.7 by experts), practical (scores of 3.9-4.1 from students), and effective, with critical thinking scores improving from 62.5 to 77.5 (a 24% increase). Local culture integration boosted student engagement and conceptual understanding. The AR application integrated with Bima's local culture proved effective as an innovative learning medium, supporting critical thinking development and cultural preservation.
Keywords: Augmented Reality, Bima's Local Culture, Critical Thingking

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1. INTRODUCTION

Advances in educational technology have significantly influenced the learning media used, particularly those supported by computers. Current technological progress presents both a challenge and an opportunity for educators to enhance the quality of classroom learning processes. As professional educators, teachers are required to master technology and utilize it effectively in classroom instruction. Technology-based learning processes aim to improve educational quality, thereby enhancing communication and information exchange between teachers and students. Computer-Assisted Instruction (CAI) plays a dominant role in elevating learning quality, as it enables teachers and students to engage in varied and enjoyable learning experiences (Salahuddin & Syahrir, 2020). Computer-assisted learning media have proven effective in higher education settings(Salahuddin & Yamin, 2021).

In practice, many teachers still lack understanding of how to use technology and how to appropriately introduce local culture to younger generations. Observable evidence indicates that digital literacy among the community in Bima remains low. Observations conducted at SMPN 3 Woha indicate that teachers' digital literacy at that school is still limited: 68% of teachers reported lacking confidence in using digital platforms for instruction because of insufficient knowledge about digital platforms or how interactive media can be used in teaching. This situation hinders the use of digital platforms to introduce local culture interactively, even though such integration has the potential to improve students' critical thinking skills (Salahuddin, 2021; Ennis, 2011). Therefore, an intervention that combines technology training for teachers and the development of digitally based local-culture learning modules is needed to enhance students' critical thinking and to preserve local culture.

Teachers need to design learning experiences that develop students' critical thinking skills (Salahuddin et al., 2024). (Salahuddin, 2023) and (Salahuddin & Ramdani, 2021) define critical thinking as reflective thought grounded in reasonable rationale and focused on deciding what to believe and what to do. Observations also show that students' critical thinking ability at SMPN 3 Woha has not yet reached an adequate level. Classroom observations and initial assessments indicate that most students tend to give descriptive answers, struggle to identify assumptions, evaluate evidence, or formulate alternative solutions when faced with open problems related to local contexts. From observations in three classes, 62% of students rarely ask critical questions and only 18% can construct a brief argument supported by relevant evidence; pretest scores for critical thinking likewise fall in the low category. This condition is closely related to teacher-centered instructional practices and limited digital literacy among educators, so multimodal and interactive local-culture learning resources are rarely used to promote analysis and reflection. Therefore, an intervention that combines digital literacy training for teachers, the development of local-culture learning modules that require higher-order reasoning, and authentic assessment to monitor students' critical-thinking development is a strategic step to implement. Ennis, (2011) argues that critical thinking plays a crucial role in achieving learning objectives.

One effective approach to address this problem is the use of appropriate instructional media coupled with the selection of suitable pedagogical approaches. The selection of engaging media and the right teaching approach will maximize students' potential, including critical thinking, while also leveraging such media to reintroduce and preserve Bima's local culture, which had previously been neglected, through the learning process. The use of technology aims to make the learning process more engaging, motivating, and attractive (Facione, 2015). Interactive learning media can also stimulate critical thinking abilities (Salahuddin & Syahrir, 2020). Various instructional media have already been developed to support the learning process, including media using Google SketchUp and iSpring Suite 88, multimedia flipbooks (Rossano et al., 2020), visual media (Nurwijayanti et al., 2019), and Augmented Reality (AR)-based media (Andini et al., 2018; Usa & Samil, 2022). One promising medium that can help enhance students' critical thinking is 3D augmented reality learning media (Flores-Bascuñana et al., 2020). AR blends the real and virtual worlds by obtaining informational data such as graphics, audio, sensory input, touch, smell, and taste—from the real-world environment to enable users to interact with virtual images (Ibili et al, 2020). The combination of graphics, text, video, animation, and sound packaged in an engaging, easy-to-understand, and clear format constitutes interactive multimedia (Mustaqim & Kurniawan, 2017). Furthermore, the selection of AR technology has received positive responses and successfully attracts students' attention (Nurdewanto et al., 2018 ; Papanastasiou et al., 2018).

Augmented Reality (AR) offers advantages that are more relevant and strategic compared to conventional instructional media and other digital technologies in the context of developing critical thinking abilities and preserving Bima's local culture. Unlike static media such as flipbooks, two-dimensional visuals, or traditional 3D simulation software (e.g., Google SketchUp), AR integrates virtual objects directly into the real environment through devices used by students, thereby enabling deeper and more meaningful contextual interaction. This integration creates a multimodal learning experience—combining graphics, text, video, animation, and sound within a perceived real space—so that students do not merely passively receive information but actively analyze, compare, and evaluate relationships between virtual objects and the surrounding real cultural contexts.

AR's strength in stimulating critical thinking is reflected in students' ability to explore cultural objects interactively, pose questions about their functions and meanings, and test alternative interpretations through dynamically adjustable simulations. For example, when students learn about traditional musical instruments or Bima customs through AR, they can rotate objects, observe them from multiple angles, and access supplementary information that triggers critical reflection on values, history, and socio-cultural context. This differs from static interactive multimedia, which, although engaging, tends to restrict students to predetermined navigation paths and thus less effectively encourages open exploration and alternative reasoning.

From the perspective of local cultural preservation, AR possesses stronger relevance because it can present authentic cultural representations while remaining accessible to younger generations. By displaying cultural objects in 3D format that can "appear" in classrooms or students' home environments, AR creates stronger emotional and cognitive experiences that foster engagement and interest in further learning. Additionally, AR enables the integration of cultural elements difficult to realize in physical form (e.g., recordings of elders' voices, animated reenactments of traditional ceremony processes, or visualizations of artifact transformations), thereby making cultural information more comprehensive, engaging, and easier to understand.

Empirical research also supports AR's superiority in improving learning outcomes and student engagement. Studies indicate that AR receives positive responses from students, attracts higher levels of attention, and enhances learning motivation compared to conventional media (Nurdewanto et al., 2018;Papanastasiou et al., 2018). More importantly, AR has been proven effective in stimulating critical thinking abilities through interactive, reflective, and self-exploratory learning experiences (Flores-Bascuñana et al., 2020;Ibili et al., 2020). Therefore, selecting AR as the instructional media integrated with Bima's local culture is not merely a modern technological choice but also the most relevant pedagogical strategy to achieve dual objectives: enhancing students' critical thinking abilities while preserving marginalized local culture. For this reason, the researcher chose augmented reality-based learning media. The AR learning application integrated with local culture was developed because the researcher believes that Bima's local culture needs to be preserved and introduced to younger generations so that they acquire knowledge related to Bima's local culture. This study focuses on the use of a digital augmented reality platform integrated with Bima local culture that can help improve students' critical thinking, as no previous research has examined the use of augmented reality combined with Bima local culture to enhance critical thinking abilities.

By integrating interactive media with local culture, students become more enthusiastic about developing critical thinking skills and preserving Bima's local culture. Therefore, designing media integrated with local culture is necessary one that not only emphasizes conceptual understanding but also considers students' psychological and social aspects in the learning process. One such medium is augmented reality, which directly presents Bima local cultural objects. This study is titled "Development of an Augmented Reality (AR) Learning Application Integrated with Local Culture to Improve Students' Critical Thinking." The objectives of developing AR-based learning media integrated with local culture are to enhance students' critical thinking, connect local culture as an application of mathematics in everyday life, preserve Bima's local culture among younger generations, facilitate understanding of presented material, and minimize in-class learning time. The Bima local culture referred to in this study relates to cultural buildings of Bima that will be connected to mathematics, such as Uma Lengge, Sigi Raja Pertama, Uma Panggung, and Asi Mbojo. This study is designed to be validated by several other competent lecturers until the product reaches a level suitable for use. The output of this research is a learning application using augmented reality technology integrated with local culture.

Theoretically, the developed AR application contributes significantly to the development of a pedagogical framework for mathematics learning that integrates digital technology with local wisdom, thereby enriching literature on the role of interactive media in shaping students' critical thinking abilities. Integrating AR with local cultural contexts offers a new learning model connecting mathematical abstraction with cultural reality—an area previously underexplored in mathematics education research. Practically, this application provides a concrete solution for teachers and students to improve mathematics learning efficiency through interactive, contextual, and meaningful learning experiences while serving as an instrument for preserving Bima's local culture accessible to younger generations in a modern format. Thus, this research not only produces a valid and feasible educational technology product but also offers important implications for transforming mathematics learning to be more relevant to 21st-century needs and the preservation of local cultural identity.

2. RESEARCH METHODOLOGY

This study employs the Research and Development (R&D) design by adopting the ADDIE Model (Analysis, Design, Development, Implementation, and Evaluation). The five main stages in implementing Augmented Reality (AR) Learning Media to enhance students' critical thinking abilities are: (1) Analysis, (2) Design, (3) Development, (4) Implementation, and (5) Evaluation.

In the Analysis stage, the researcher analyzed students' needs in solid geometry learning and identified learning materials suitable for AR-based media to ensure learning objectives could be achieved. In the Design stage, the researcher designed engaging and easy-to-understand AR application-based learning with varied materials for each session. This design was then validated by several competent lecturers as validators until the product was deemed feasible for use. Validation was conducted over one week, and based on validation results indicating the design was ready for use, the researcher proceeded to the Development stage to develop the AR application according to students' and teachers' needs. In the Implementation stage, lecturers implemented learning using the designed AR media to measure the improvement in students' critical thinking. The final stage, Evaluation, aimed to assess whether the objective of improving students' critical thinking was achieved and to evaluate the effectiveness of the learning design using the AR application.

This study was conducted at SMPN 3 Woha with 40 students as respondents participating in Solid Geometry learning. Participant characteristics included students aged 14–15 years, comprising 22 male and 18 female students, with heterogeneous initial mathematics abilities. Data collection instruments included questionnaires, informal interviews, and personal observations. The questionnaire consisted of 35 Likert-scale items (1–5, ranging from "Strongly Disagree" to "Strongly Agree"), divided into two sections: (1) participant personal information, and (2) 15 items in one cluster investigating students' attitudes toward the AR application integrated with local culture to enhance critical thinking.

To measure critical thinking abilities, an open-ended critical thinking test comprising 10 items was used, with a scoring rubric covering six aspects adopted from Facione, (2015): interpretation, analysis, evaluation, inference, explanation, and self-regulation. This test underwent content validity testing by three expert validators (mathematics education lecturers), and its reliability was measured using Cronbach's alpha coefficient = 0.84, indicating good internal consistency. The attitude questionnaire also was tested for reliability with a Cronbach's alpha value of 0.86.

Media validation was conducted using a scoring instrument with a Likert scale (1–5) covering content/material, visual design, user interaction, and technical quality aspects. The final validation score was calculated as the average of all validator scoring items. Validation score categorization adapted the criteria by Error (2016) and commonly used standards for learning media: scores of 1.00–1.75 = "Poor," 1.76–2.50 = "Fair," 2.51–3.25 = "Good," 3.26–4.00 = "Very Good," and 4.01–5.00 = "Extremely Good."

Data were analyzed using a mixed-methods approach (quantitative and qualitative). Quantitative data were obtained from percentages and mean scores of expert media and student questionnaires, while qualitative data were derived from suggestions, criticisms, and validators' opinions as well as observation and interview results. Data integration was conducted through triangulation, comparing questionnaire results with qualitative findings to ensure consistency and strengthen interpretation. Quantitative data were analyzed using descriptive statistics (mean, standard deviation, percentage), while qualitative data were analyzed using descriptive qualitative analysis with thematic coding to identify response patterns and recommendations for product improvement.

3. RESULT

The research results indicate that the product development process, following the established stages, successfully enhanced critical thinking through a deep learning approach and the use of Augmented Reality (AR) learning instruments integrated with local culture. This was followed by the validation stage, where expert validators assessed the product's feasibility in terms of its validity. The validation results showed that the developed product was rated as "very good," requiring no revisions. The validation was conducted by two experts covering both media and content aspects, with the results summarized in the following table.

Table 1
Product Validation Results by Media Experts

Aspects Assesed	Expert 1 Score	Expert 2 Score	Average
Visual Display Quality	4.5	4.7	4.6
Content Suitability	4.6	4.8	4.7

The validation results showed high scores (4.6–4.7), falling into the "Very Good" category. These findings align with research, which demonstrated that AR-based learning media developed using the ADDIE model are technically and pedagogically valid, while also enhancing students' critical thinking and motivation. This strengthens the conclusion that the product is suitable for further development. Subsequently, the product was implemented at the target school, SMPN 3 Woha, to gather data on the practicality and effectiveness of the developed Augmented Reality learning integrated with local culture. The following presents the practicality results.

Table 2.
Practicality Results (Questionnaire)

No	Statement	STS (1)	TS (2)	N (3)	S (4)	SS (5)	Average
1	AR application helps understand mathematics material	0	2	3	10	5	4.0
2	Local culture integration makes learning meaningful	0	1	4	8	7	4.1
3	AR use makes students more active	1	1	3	9	6	3.9
4	Application is easy to use and understand	0	2	2	11	5	4.0
5	AR improves critical thinking skills	0	1	5	10	4	3.9

The questionnaire showed high scores on indicators of ease of use, visual appeal, and ability to increase student engagement. The high questionnaire scores active student engagement support the product's effectiveness. states that AR use in STEM learning, including mathematics, can increase motivation, engagement, and contextual situated learning. This confirms that the developed AR application is practical, engaging, and supports interactive learning.

Effectiveness Results of Augmented Reality (AR) Learning Application Development Integrated with Local Culture

Effectiveness Results (Critical Thinking Test)

There was a significant improvement from pre-test to post-test across all critical thinking indicators.

Table 3.
pre-test to post-test across all critical thinking indicators.

Indicator	Pre-test	Post-test	Improvement
Interpretation	65	80	15
Analysis	62	78	16

Evaluation	60	76	16
Inference	64	79	15
Explanation	63	77	14
Self-regulation	61	75	14
Total Average	62.5	77.5	15.0

The significant improvement in critical thinking test scores demonstrates that AR is capable of enhancing students' critical thinking significantly compared to conventional methods in geometry topics. The average score increase from 62.5 to 77.5, representing a total mean increase of 15 points, proves the application's effectiveness in stimulating critical reasoning. Interview findings revealed that integrating Bima culture makes the learning media more meaningful. The use of AR media with interactive visuals and intuitive design also contributed to a reduction in extraneous cognitive load. These results align with field observations demonstrating the application's ease of use and effectiveness. It can be concluded that teachers stated the application made students more enthusiastic, students appreciated the AR visuals, and validators rated the local culture integration as relevant.

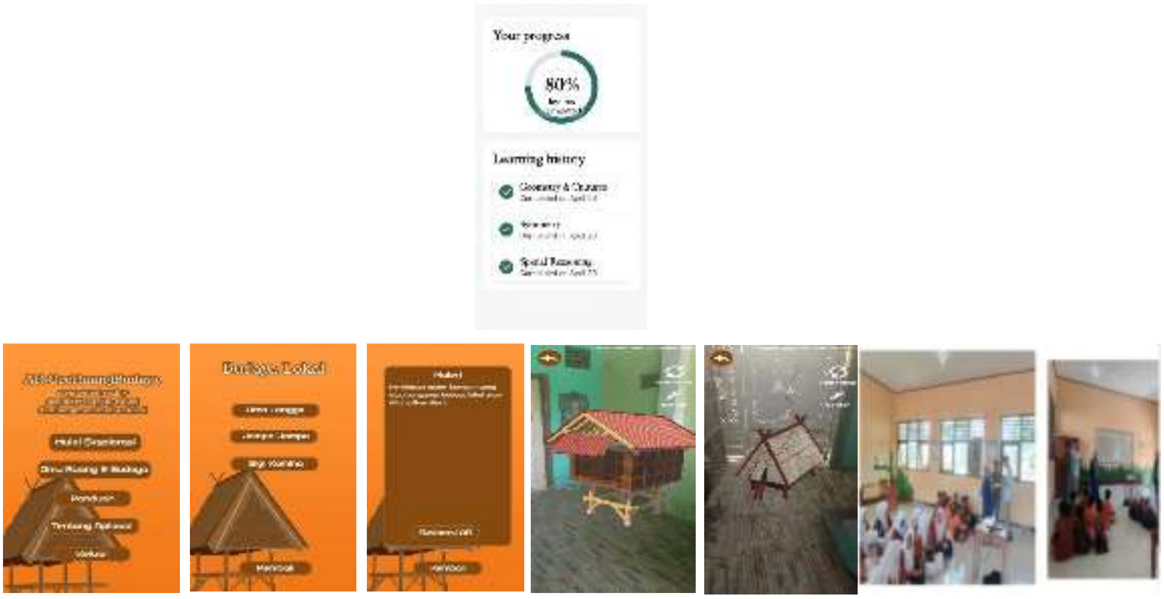

Figure 1. Interface of the AR geometry application and documentation of result.

4. DISCUSSION

4.1. Validity of AR Application Integrated with Local Culture

Validation results from two media and content experts yielded exceptionally high average scores: 4.6 for visual display quality and 4.7 for content suitability. These scores fall into the category of "Extremely Good" and indicate that the developed product meets the technical and pedagogical standards necessary for learning implementation.

The high visual quality score demonstrates that the AR interface successfully presents 3D objects of Bima local culture (Uma Lengge, Sigi Raja Pertama, Uma Panggung, Asi Mbojo) clearly and engagingly. This is not merely about aesthetic appeal; high-quality visualizations directly reduce extraneous cognitive load, allowing students to focus their mental resources on analyzing geometric structures rather than struggling to comprehend objects. According to Cognitive Load Theory (Sweller et al, 2011), when visual presentation is intuitive, working memory capacity is freed for relevant cognitive processing—essential for critical thinking tasks such as analysis and evaluation.

The high content suitability score confirms that learning content integrated with Bima local culture aligns with the mathematics curriculum and junior high school students' cognitive characteristics. Ethnomathematics integration (D’Ambrosio, 1985;Rosa & Orey M. A, 2011) creates meaningful contexts where abstract mathematical concepts become concrete through cultural artifacts. When students examine the triangular roof structure of Uma Lengge through AR, they do not passively receive information about triangles; they actively analyze how ancient architects applied geometric principles to achieve aesthetic and functional goals. This contextualization transforms geometry from abstract formula into meaningful problem-solving, directly engaging interpretation, analysis, and evaluation skills.

The systematic implementation of the ADDIE model (Branch, 2009) contributed to this validity by ensuring thorough needs analysis, student-centered design, interactive prototype development, careful implementation, and continuous evaluation. This systematic approach prevents "blind adoption" of technology and instead produces AR media pedagogically aligned with critical thinking development goals (Selwyn, 2011).

4.2. Practicality of AR Application in Learning

Practicality test results through questionnaires and observations showed positive responses from students and teachers. Average scores across five practicality indicators ranged from 3.9 to 4.1 on a maximum 5.0 scale. The highest-scoring indicator was "Local culture integration makes learning meaningful" (4.1), followed by "AR application helps understand mathematics material" and "Application is easy to use and understand" (both 4.0). Students recognize that the geometric objects they are studying are part of their own cultural heritage, they engage more deeply with the material. This emotional and cultural connection creates cognitive engagement essential for critical thinking. Johnson-Glenberg, (2018) demonstrated that AR/VR within CRP frameworks enhances spatial reasoning, engagement, and motivation toward mathematics. In the Bima context, students studying traditional architecture through AR are not studying distant abstractions; they are investigating their ancestors' engineering heritage. This personal relevance transforms passive observation into active inquiry—students ask why roofs have certain angles, how structures remain stable, and what mathematical principles guide the design. These questions represent critical thinking in action.

The high usability score indicates that the user interface and experience were well-designed despite AR technology's inherent complexity. Ibili et al., (2020)noted that poorly designed AR can become a cognitive barrier. When students struggle with navigation or controls, their cognitive resources are consumed by technical difficulties rather than mathematical analysis. The intuitive design observed in this study minimizes this extraneous load, allowing students to focus on manipulating 3D objects, exploring multiple viewpoints, and testing geometric hypotheses activities that directly engage analysis, inference, and explanation skills.

Field observations revealed that students were more active and enthusiastic using the AR application. This active engagement is an important practicality indicator. Akbar et al, (2020) found that AR in STEM learning increases motivation, engagement, and situated learning. Unlike passive media where students receive predetermined information, AR enables students to rotate Uma Lengge models, examine structures from multiple angles, and manipulate parameters to test geometric relationships. This hands-on exploration requires students to form hypotheses ("If I change this angle, the structure becomes unstable"), test through manipulation, and evaluate outcomes engaging the full critical thinking cycle of interpretation, analysis, evaluation, inference, and explanation.

Some students provided neutral or less-positive responses (particularly on items 3 and 5), likely due to variations in digital literacy levels and smartphone availability. Some required more time to adapt to AR technology, indicating that intensive scaffolding is necessary during early implementation. This suggests that although AR is powerful for critical thinking development, its effectiveness depends on adequate scaffolding to ensure all students can access interactive learning experiences.

4.3. Effectiveness in Enhancing Critical Thinking

The most significant finding is the improvement in students' critical thinking abilities measured through pre-test and post-test. Average scores increased from 62.5 to 77.5 (a 15-point increase) across all six critical thinking indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation.

The highest improvements occurred in analysis and evaluation, revealing AR's unique contribution to critical thinking. When students manipulate 3D Uma Lengge models, they must actively analyze roof structures, slope angles, and building proportions, connecting these observations with mathematical concepts such as triangles, angles, and ratios. This is not passive pattern recognition; it requires breaking down complex structures into component elements (analysis) and judging the validity of geometric relationships (evaluation). Flores-Bascuñana et al., (2020) demonstrated similar findings with 3D AR in geometry, showing significant critical thinking improvements compared to conventional methods. AR's immersive experience enables students to visualize abstract concepts concretely and interactively. When students can rotate, zoom, and manipulate architectural objects, they engage spatial reasoning essential for geometric analysis. They do not merely memorize that "a triangle has 180 degrees"; they discover this by measuring angles on actual traditional roof structures, testing whether different configurations remain stable, and evaluating which designs optimize both aesthetics and structural integrity.

Improvements in interpretation and inference indicate that students can meaningfully interpret visual information from AR objects and draw mathematical conclusions from their observations. When students examine geometric patterns on Asi Mbojo (traditional Bima fabric) through AR, they not only recognize patterns but interpret principles of symmetry, translation, and rotation embedded within them. Inference develops when students predict shape or size changes based on manipulating specific parameters. AR presents multiple representations simultaneously (visual, spatial, numerical), requiring students to integrate information across modalities. This multimodal integration forces deeper cognitive processing than single-mode presentation. Students must synthesize visual patterns with mathematical rules, connecting what they see (symmetrical fabric patterns) with abstract principles (geometric transformations). This synthesis process is interpretation. When students then predict how changing one element affects the entire pattern, they engage inference drawing conclusions beyond immediate observation.

Improvements in explanation and self-regulation reflect AR's role in promoting articulation and autonomous learning. Explanation developed because the AR application encourages students to articulate understanding verbally to teachers and peers or through written tasks. When students manipulate 3D objects and observe outcomes, they must explain why certain configurations work and others do not. This requires connecting manipulation actions with mathematical principles, articulating reasoning processes, and justifying conclusions—core explanation skills. Self-regulation improved because AR learning provides students freedom to explore objects at their individual learning pace, make mistakes, and correct them without pressure. This autonomy fosters metacognitive monitoring: students plan their exploration strategies, monitor their understanding, and adjust approaches when confused.

These improvements align with Cognitive Load Theory Sweller et al, (2011). Effective learning occurs when extraneous cognitive load is minimized and relevant cognitive load is optimized. AR's intuitive and interactive visual design reduces unnecessary cognitive burden, allowing working memory to focus on processing information relevant to building understanding schemas. Ibáñez and (Ibáñez & Delgado-Kloos C, 2018) supported this, showing AR decreases extraneous load, increases germane load, and maintains student motivation in science and mathematics learning. The observed ease of application use and sustained motivation in this study confirm this mechanism.

5. CONCLUSION

The developed AR application makes a significant contribution to mathematics learning, particularly in solid geometry. Integrating local cultural objects (Uma Lengge, Asi Mbojo, Sigi Raja Pertama, Uma Panggung) with geometric concepts enables students to perceive the relevance of mathematics in their daily lives and their own cultural heritage. The application not only assists students in understanding concepts of triangles, angles, and ratios, but also demonstrates how their ancestors applied mathematical principles in designing traditional buildings that are aesthetic, functional, and resilient to natural environmental conditions.

The unique contribution of this research is the successful integration of Bima ethnomathematics with AR technology, which yields dual implications: enhancing 21st-century skills while simultaneously preserving local cultural heritage. Many younger students are beginning to lose knowledge of their local culture due to the influences of globalization and urbanization. Through this AR application, students not only learn mathematics but also recognize, understand, and appreciate their cultural heritage.

Although this study yields significant findings, several limitations must be acknowledged. First, the research was conducted only in a single school (SMPN 3 Woha) with 40 students; therefore, generalizing the findings to a broader population requires additional research in other schools with different characteristics. Second, variations in students' digital literacy levels and the availability of adequate smartphone devices affect the application's practicality; some students required more time to adapt to AR technology. Third, this study measured critical thinking improvement only in the short term (pre-test and post-test), so it cannot be determined whether these improvements persist over a longer period. Recommendations for future research include conducting similar studies with larger and more diverse samples (multiple schools, different regions) to test the generalizability of findings. AR proved effective in reducing cognitive load and facilitating meaningful learning.

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