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THE EFFECTIVENESS OF AUGMENTED REALITY LEARNING MEDIA INTEGRATING TORAJA CARVING ETHNOMATHEMATICS ON STUDENTS' MATHEMATICAL PROFICIENCY

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ABSTRACT

This study aims to investigate the effectiveness of Augmented Reality (AR) learning media integrating Toraja carving ethnomathematics on the mathematical proficiency of ninth-grade junior high school students in Palopo. The research employed a quasi-experimental design using a pre-test and post-test model to measure the impact of AR learning media on students' mathematical skills. The participants consisted of 150 students selected from six schools through purposive and random sampling techniques. The research instruments comprised a mathematical proficiency test and a questionnaire developed based on five indicators: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. Data were analyzed using the Wilcoxon Signed-Rank Test, as the dataset was not normally distributed. The results indicate a significant improvement in students' mathematical proficiency after the implementation of AR learning media, as evidenced by the significance value of the Wilcoxon Signed-Rank Test, which is 0.000 and lower than 0.05. The integration of AR technology with local cultural elements of Toraja carvings successfully fostered a contextual, interactive, and meaningful learning environment. This study implies that can serve as an innovative pedagogical approach to enhance mathematical proficiency while promoting the preservation and appreciation of local culture in mathematics education.

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INTRODUCTION

The development of digital technology in education has brought significant changes to the way students learn and teachers teach. The transformation from conventional learning to technology-based learning has become a global trend that continues to grow alongside rapid advances in information and communication technology. One of the most prominent innovations gaining increasing attention is the use of Augmented Reality (AR) as an interactive learning medium capable of merging the real and virtual worlds into a single immersive learning experience. AR is a technology that enables the embedding of digital information—such as three-dimensional models, text, or holographic elements—into real environments directly and in real-time. Through this technology, users can interact with virtual objects as if they were part of the surrounding real world (Candido & Cattaneo, 2025). Such interaction is facilitated by device systems designed to detect physical areas where virtual elements are displayed. Users engage with AR in real-time through mobile devices, creating an informational space that integrates the physical environment with contextual media (Mercier et al., 2025). In the context of mathematics education, the implementation of AR technology is believed to assist students in understanding abstract mathematical concepts in a more visual and meaningful manner, particularly when integrated with cultural contexts that are familiar and relevant to their everyday lives (Widodo et al., 2024).

Field observations indicate that Indonesian students' mathematical abilities remain relatively low (Damanik & Handayani, 2023). According to the Programme for International Student Assessment (PISA) 2022 report, Indonesian students' mathematics scores are still below the international average, ranking 70th out of 81 OECD countries (Alfaruqi & Nurwahidah, 2025; Yanto & Rahaju, 2024). This finding suggests that students' mathematical proficiency requires serious attention. One contributing factor to this low performance is the dominance of conventional learning models, which often fail to facilitate higher-order thinking skills. As Kilpatrick defines, mathematical proficiency refers to an individual's ability to understand, apply, and reason mathematically to solve problems across various real-life contexts. It encompasses five interrelated components—conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Syarifuddin, 2025). Therefore, it is crucial to develop innovative and contextual learning approaches that enable students to construct their mathematical proficiency meaningfully and sustainably.

In response to this phenomenon, various studies have demonstrated that technology-based learning media can positively contribute to student learning outcomes. For instance, Hazzam and Wilkins (2023) found that the use of technology in learning could enhance both academic achievement and student satisfaction. Similarly, research conducted by Zhang (2024) indicated that the integration of technology into learning significantly improves student performance and engagement. These findings align with the study by Safitri et al. (2025), which concluded that Augmented Reality (AR)

integration offers a transformative approach and can increase student involvement in the learning process. In addition, AR technology has shown potential as an effective and engaging tool to support students with dyscalculia (Alsolami & Allinjawi, 2025). However, most of these studies have been limited to the general application of AR and have not specifically explored its integration with local cultural elements, which could further enrich the meaningfulness of students' learning experiences.

Ethnomathematics emerges as an approach that connects mathematics with cultural values and community practices. According to D'Ambrosio (2006), ethnomathematics is the study of how people in various cultures understand, articulate, and use mathematical concepts in their daily lives. Integrating ethnomathematics into learning enables students to recognize that mathematics is not an isolated discipline but rather an integral part of human culture, living and dynamic (Nugraha & Nessa, 2020). In this context, Toraja carvings represent a significant aspect of Indonesia's cultural heritage, containing rich mathematical elements, such as geometric transformations (Nugraha, 2019). Introducing mathematical concepts through learning media based on Toraja ethnomathematics can simultaneously strengthen students' cultural identity and enhance the relevance of learning, making mathematics more meaningful and connected to their everyday experiences.

Several previous studies have attempted to combine ethnomathematics with modern learning media. Aini et al. (2025) reviewed several studies examining this integration. Research by Prastitasari et al. (2025) developed e-Card Edudaya, a digital media based on ethnomathematics, which shows significant potential in supporting mathematics learning. Umri et al. (2025) developed AR-based learning media integrating Prambanan Temple ethnomathematics, while Damayanti et al. (2025) created AR-based learning media integrated with the ethnomathematics of Joglo traditional houses. Despite these advancements, there remains a research gap concerning the integration of AR technology with Toraja carving ethnomathematics to enhance students' mathematical proficiency.

The novelty of this study lies in examining the effectiveness of Augmented Reality (AR)-based learning media integrated with Toraja carving ethnomathematics. This learning media not only presents Toraja carvings in a virtual format but also links them to geometric transformation concepts, such as reflection, translation, rotation, and dilation. This approach is grounded in Vygotsky's constructivist theory, which emphasizes the importance of social and cultural contexts in constructing understanding (Azis et al., 2025), as well as multimodal learning theory, which posits that multisensory engagement can enhance knowledge retention and transfer (Wijayanti & Laili, 2024). Consequently, this study offers an innovative learning media that integrates cognitive, affective, and cultural dimensions into a single, meaningful learning experience.

Based on this background, this study focuses on addressing the question of how effective the use of Augmented Reality (AR) learning media based on Toraja carving ethnomathematics is in improving the mathematical proficiency of ninth-grade junior high school students in Palopo City. This research is expected to contribute to the development of mathematics learning media that not only aim to improve cognitive skills but also foster an appreciation of local cultural values. Furthermore, the findings of this study are anticipated to serve as a valuable reference for teachers and learning media developers in designing mathematics instruction that is more contextual, innovative, and rooted in Indonesian cultural heritage.

METHOD

This study employed a quantitative approach with a quasi-experimental design. The approach aimed to evaluate the effectiveness of Augmented Reality learning media integrated with Toraja carving ethnomathematics on students' mathematical proficiency. The variables examined included the use of AR learning media as the treatment variable and students'

mathematical proficiency as the dependent variable. The study focused on analyzing the differences in students' mathematical proficiency scores before and after the implementation of AR learning media.

The population of this study consisted of all junior high school students in Palopo City. From this population, a total of 150 students from six different schools were selected as the sample. The selection of schools was carried out using a purposive sampling technique, taking into account several factors such as the availability of facilities, school readiness, and the suitability of the learning materials currently taught by mathematics teachers. Furthermore, from each selected school, student classes were determined using a random sampling technique so that every class had an equal opportunity to become a respondent..

The research instruments were developed based on five key indicators of mathematical proficiency, namely conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. The measurement was conducted using two types of instruments: an essay test to assess the first four indicators and a Likert-scale questionnaire to evaluate the productive disposition indicator.. Prior to their use in the study, both instruments underwent validity and reliability testing to ensure the accuracy and consistency of the measurement results.

The data in this study were analyzed using the non-parametric Wilcoxon Signed-Rank Test to determine differences in students' mathematical proficiency before and after the implementation of the learning media. This analysis technique was selected because the normality test using Kolmogorov-Smirnov indicated the data were not normally distributed. By employing this test, the researchers were able to assess the significance of changes in students' mathematical proficiency following the use of the AR-based learning media. All statistical analyses were conducted using SPSS 25 software to ensure that the results were valid, objective, and scientifically accountable.

RESULT AND DISCUSSION

Result

Data were collected through the administration of tests and questionnaires to the 150 students selected as the sample. Both the pre-test and post-test instruments consisted of four essay questions, while the pre-experiment and post-experiment questionnaires each contained 12 statements. The validity of the test instruments was evaluated through expert assessment, involving three specialists in mathematics education. Subsequently, the validity level of the test instruments was calculated using Aiken's V formula.

Table 1. Pre-Test Instrument Validity Results

Aspek	$\sum s$	V	$\bar{V}$
1	8	0,89	0,78
2	8	0,89	
3	6	0,67	
4	5	0,56	
5	7	0,78	
6	8	0,89	

Table 2. Post-Test Instrument Validity Results

Aspek	$\sum s$	V	$\bar{V}$
1	9	1,00	0,81
2	8	0,89	
3	6	0,67	
4	6	0,67	
5	7	0,78	
6	8	0,89	

Based on Table 1, the average V value calculated using Aiken's V formula for each assessed aspect was 0.78, indicating that the pre-test instrument demonstrated a high level of validity (Zakiyah & Kartika, 2024). According to Table 2, the average V value for the post-test instrument was 0.81, suggesting a very high level of validity. Therefore, both test instruments are considered appropriate and suitable for measuring students' mathematical proficiency.

The questionnaire instruments in this study also underwent validity and reliability testing using SPSS. The results presented in Table 3 indicate that all items in the questionnaire met the criteria for both validity and reliability, with calculated r values exceeding the critical r (0.159) at a 5% significance level, and Cronbach's Alpha values exceeding 0.60. Therefore, both the pre-experiment and post-experiment questionnaires are deemed suitable for accurately and consistently measuring students' productive disposition.

Table 3. Questionnaire Item Validity and Reliability Results

Pre-Experiment Questionnaire			Post-Experiment Questionnaire		
item no-	r-calculated	Cronbach's Alpha	item no-	r-calculated	Cronbach's Alpha
1	0,400	0,810	1	0,246	0,844
2	0,331		2	0,187	
3	0,543		3	0,207	
4	0,543		4	0,222	
5	0,545		5	0,406	
6	0,660		6	0,261	
7	0,656		7	0,411	
8	0,660		8	0,352	
9	0,646		9	0,274	
10	0,531		10	0,214	
11	0,669		11	0,381	
12	0,621		12	0,565	

Figure 1 illustrates students' mathematical proficiency levels before the implementation of Augmented Reality (AR) learning media integrated with Toraja carving ethnomathematics. Overall, the pre-test results indicate that students' mathematical abilities were generally low to moderate across most measured indicators. Descriptive analysis shows that the average scores for each indicator were as follows: conceptual understanding 62.17, procedural fluency 66.83, strategic competence 56.83, adaptive reasoning 53.17, and productive disposition 70.56.

Meanwhile, the distribution of proficiency categories revealed that 62.67% of students fell into the moderate category, while the remainder were in the low category. This pattern suggests that prior to the use of AR-based learning media, most students were unable to fully optimize their mathematical thinking skills, particularly in reasoning and selecting problem-solving strategies. These pre-test results serve as an

important benchmark for evaluating the effectiveness of AR-based learning media in subsequent learning stages.

Figure 2 illustrates students' mathematical proficiency levels after the implementation of Augmented Reality (AR) learning media integrated with Toraja carving ethnomathematics. Overall, the post-test results indicate an improvement in students' abilities compared to the pre-test across all measured indicators. The average scores for each indicator were: conceptual understanding 69.00, procedural fluency 81.83, strategic competence 68.83, adaptive reasoning 74.17, and productive disposition 75.00, showing clear increases from the pre-test scores.

Based on the distribution of proficiency categories, 2.67% of students fell into the low category, 80.67% into the moderate category, and 16.67% achieved a high level of mathematical proficiency. These findings demonstrate that the use of AR-based learning media positively impacted students' mathematical skills, particularly in procedural fluency and productive disposition, which recorded the highest average scores. The improvement suggests that AR-based mathematics learning media can help students understand abstract concepts in a visual, interactive, and contextual manner through richly patterned and intricate representations of Toraja carvings. The post-test results further reinforce evidence that AR-based learning media integrated with Toraja ethnomathematics has the potential to be an effective innovation for comprehensively developing students' mathematical proficiency.

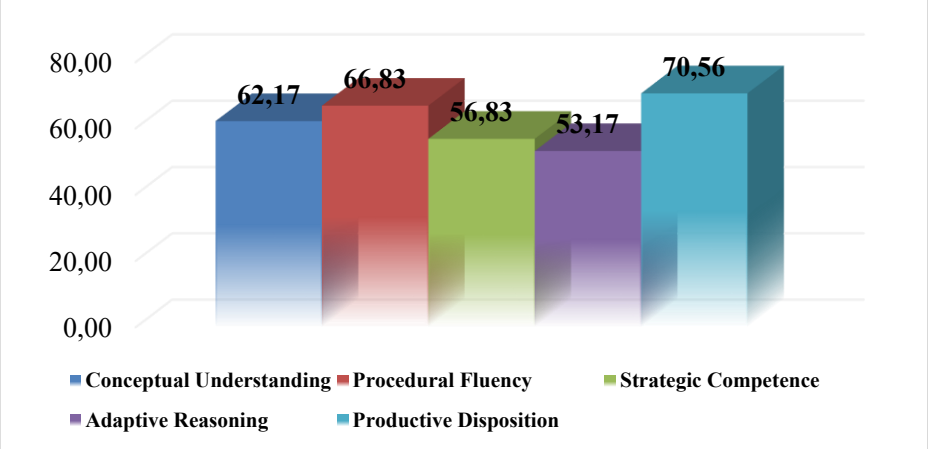

Figure 1. Students' Mathematical Proficiency Before Using AR Learning Media

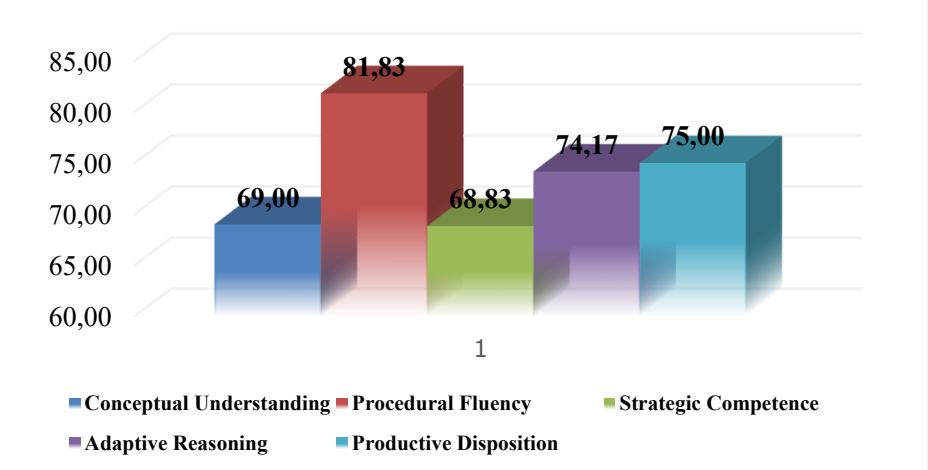

Figure 2. Students' Mathematical Proficiency After Using AR Learning Media

Next, a normality test was conducted on students' mathematical proficiency data before and after the implementation of AR learning media. This test was performed to determine the data distribution and to select the appropriate statistical test for hypothesis testing. The results of the normality analysis are presented in Table 4.

Table 4. Normality Test Result

	Statistic	Df	Sig.
MP_pra	,072	150	,052
MP_post	,076	150	,034

The normality test results showed that students' mathematical proficiency data before the implementation of AR learning media had a significance value of 0.052, which is greater than the 0.05 significance level, indicating that the data were normally distributed. In contrast, the data after using AR learning media had a significance value of 0.034, which is less than 0.05, indicating that the data were not normally distributed. Based on these findings, the most appropriate technique for hypothesis testing in this study is the non-parametric Wilcoxon Signed-Rank Test.

Figure 3 illustrates the comparison of students' mathematical proficiency scores before and after learning with AR-based media integrated with Toraja carving ethnomathematics. The calculations revealed that 15 students experienced a decrease in scores after the learning intervention, while 133 students showed increased scores. Additionally, 2 students had the same pre-test and post-test scores. These results indicate that the majority of students improved their mathematical proficiency after participating in the AR-based learning. Therefore, the use of AR-based learning media integrated with Toraja ethnomathematics had a positive impact on enhancing students' mathematical proficiency.

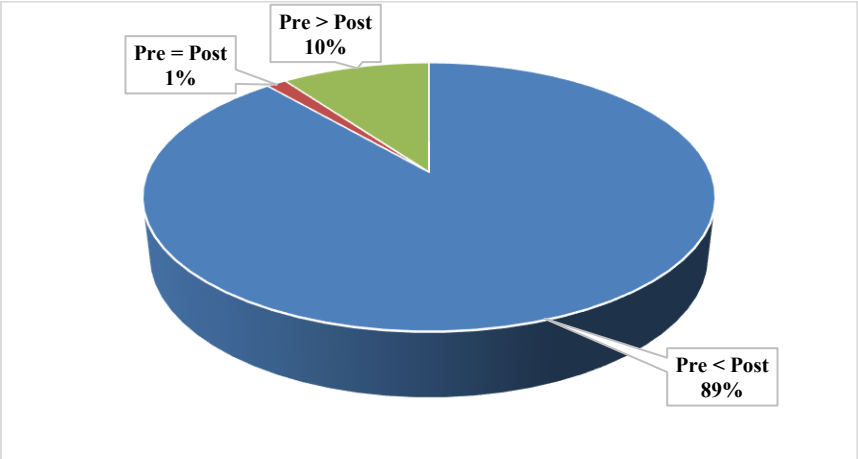

Figure 3. Comparison of Students' Mathematical Proficiency Scores

The Wilcoxon Signed-Rank Test was applied to evaluate the effectiveness of AR-based learning media in enhancing students' mathematical proficiency. This non-parametric test was used to determine whether there were significant differences between the pre-test and post-test results following the implementation of AR-based learning in the classroom. The results of the Wilcoxon analysis are presented in Table 5. Based on the results of the Wilcoxon Signed-Rank Test, the Z value was -9.926 with a significance level of Asymp. Sig. (2-tailed) = 0.000. Since this significance value is less than the 0.05 threshold, it can be concluded that there is a significant

difference between students' mathematical proficiency scores before and after the implementation of AR-based learning media. These results indicate that the use of Augmented Reality learning media integrated with Toraja carving ethnomathematics is effective in improving the mathematical proficiency of junior high school students in Palopo City.

Table 5. Wilcoxon Test Result

	MP_post - MP_pra
Z	-9,926[b]
Asymp. Sig. (2-tailed)	,000

Discussion

The findings of this study indicate that the use of Augmented Reality learning media integrated with Toraja carving ethnomathematics significantly enhanced the mathematical proficiency of junior high school students in Palopo City. This is evidenced by the Wilcoxon Signed-Rank Test, which yielded a significance value of 0.000 < 0.05, indicating a significant difference between students' mathematical proficiency scores before and after the intervention. The majority of students showed an improvement in their scores. These findings confirm that AR-based learning media, when integrated with local cultural contexts such as Toraja carvings, can create a meaningful learning experience and foster a comprehensive enhancement of students' mathematical proficiency.

The first aspect showing improvement is conceptual understanding. Through the use of AR-based learning media in mathematics, particularly on the topic of geometric transformations, students were able to visualize transformations such as reflection, translation, rotation, and dilation more concretely, linked to the patterns of Toraja carvings. This interactive visual representation helped students understand the relationships between transformation concepts and the ethnic motifs. These findings align with Fadhila et al. (2023), who stated that AR-based visualization can strengthen students' mental construction of abstract mathematical concepts. Therefore, AR-based media play a crucial role in transforming the learning process from abstract to more concrete and contextual, thereby enhancing students' conceptual understanding.

Next, improvement was also observed in students' procedural fluency. After learning with AR-based media, students were better able to apply problem-solving steps systematically and efficiently. The interactivity provided by AR allowed students to practice repeatedly with immediate feedback, helping them identify procedural errors and correct them independently. These findings support the study by Rahmadhani & Helsa (2025), which explained that AR enhances students' active engagement and strengthens procedural skills through visual and kinesthetic practice. Therefore, AR-based media not only improve procedural accuracy but also reinforce the automation of fundamental mathematical skills.

The aspect of strategic competence, which refers to students' ability to design and apply problem-solving strategies, showed significant improvement after using AR-based learning media. Through AR-based mathematics learning, students were encouraged to explore various alternative strategies via simulations of contextual situations inspired by Toraja carving ethnomathematics. For example, when students were tasked with determining the starting point of a known geometric transformation composition, they practiced strategic thinking to select the most efficient solution method. These findings align with Kusumaningrum et al. (2025), who stated that strategic competence develops through reflective problem-solving experiences grounded in real-world contexts. Thus, the implementation of AR-based media provides students with opportunities to develop independent thinking while honing

their strategic skills through authentic and meaningful learning experiences (Walkington et al., 2025).

Students' adaptive reasoning also showed considerable improvement. AR-based media integrated with ethnomathematics encouraged students to connect mathematical concepts with new and diverse cultural contexts, requiring them to adjust their thinking strategies to varied situations. Students were not only expected to provide correct answers but also to explain the reasoning behind their solutions based on the context presented by the media. This aligns with Vygotsky's constructivist theory, which emphasizes the importance of social interaction and cultural context in developing reasoning (Azis et al., 2025). Therefore, the use of AR-based ethnomathematics media expands students' adaptive thinking skills through meaningful and reflective learning processes.

The final aspect, productive disposition, also improved after learning with AR-based media. Students' engagement in interactive, visual, and meaningful learning experiences fostered a positive attitude toward mathematics. They perceived mathematics not merely as symbols and numbers but as connected to cultural values and real-life contexts. This positive attitude encouraged intrinsic motivation to learn more deeply and to confidently tackle challenges in solving mathematical problems (Zapata et al., 2024). These findings are supported by Putri et al. (2025), who reported that AR-based media effectively help students understand mathematical concepts more deeply, enjoyably, and meaningfully, while also fostering self-confidence and independence in learning. Thus, AR-based learning not only enhances cognitive abilities but also strengthens students' affective aspects.

Overall, the findings of this study confirm that Augmented Reality learning media integrated with Toraja carving ethnomathematics is effective in enhancing all aspects of students' mathematical proficiency, including conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. The integration of AR technology with local cultural values creates contextual, engaging, and meaningful learning experiences, while also strengthening students' character and cultural identity. Therefore, this study provides both theoretical and practical contributions to the development of innovative mathematics learning approaches that combine technology and culture, and opens opportunities for broader applications in the context of ethnomathematics from other regions in Indonesia.

CONCLUSION

The use of Augmented Reality learning media integrated with Toraja carving ethnomathematics has been proven effective on improving students' mathematical proficiency, covering conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition. This improvement occurs because AR media provides interactive, contextual learning experiences while integrating local cultural values into mathematics instruction. Theoretically, this study reinforces the view that the integration of immersive technology with cultural contexts can serve as an innovative approach in mathematics education. Practically, the findings imply that teachers can utilize AR as a local wisdom-based learning tool to develop students' mathematical proficiency comprehensively. However, this study has limitations regarding the sample size and the specific cultural context applied. Therefore, it is recommended that future research expand the scope to include other regions and ethnomathematical contexts, so that the results can be generalized more broadly.

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Augmented Reality-based mathematics learning media grounded in Toraja carving ethnomathematics, as an effort to enhance students' mathematical proficiency and enrich innovations in technology- and culture-based learning.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization, methodology, data curation, formal analysis, writing – original draft, visualization, and project administration.
Author 2: Investigation, software development, and provision of resources.
Author 3: Validation of research findings and writing – review & editing.

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