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Innovative Mathematics Learning: The Impact of Augmented Reality and Ethnomathematics on Communication Skills

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ABSTRACT

The integration of digital technology with a cultural approach has become an important innovation in mathematics education to enhance meaningful learning. However, there is still limited research combining Augmented Reality (AR) with ethnomathematics to strengthen students' mathematical communication skills. This study aims to analyze the impact of Augmented Reality and ethnomathematics-based learning on students' mathematical communication skills. The study employed an experimental design involving 60 seventh-grade students selected randomly from eight classes at SMP Negeri 6 Langke Rembong, Ruteng, Indonesia, during the 2024/2025 academic year. The research instrument consisted of a five-item mathematical communication test, which was validated through expert judgment and empirical testing, and demonstrated satisfactory reliability based on internal consistency analysis. SPSS and CMA software were used to support data analysis. A t-test was conducted to examine differences in mathematical communication ability between the experimental and control groups after fulfilling prerequisite assumptions. The findings indicate that the integration of AR and ethnomathematics significantly improved students' ability to express mathematical ideas clearly, both orally and in written form. Additionally, students showed higher levels of cultural engagement and appreciation, which positively contributed to the development of their communication skills. This study recommends the integration of AR and ethnomathematics as a sustainable innovation in mathematics learning and suggests further research to explore its application across diverse mathematical topics and broader educational contexts.

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A. INTRODUCTION

In the 21st century, mathematics education is increasingly required to equip students not only with computational skills, but also with higher-order thinking and communication skills (Kaya et al., 2025). Mathematical communication, both oral and written, is recognized as a fundamental competency that enables students to construct, represent, and share mathematical ideas effectively (Ya-Amphan et al., 2024). International assessments such as PISA and TIMSS consistently emphasize communication as an integral part of mathematical literacy (Sari et al., 2025). Thus, the development of students' communication skills has become a global concern and a key indicator of the quality of mathematics learning.

Despite its importance, numerous studies show that students still struggle to communicate mathematically clearly and logically. In Indonesia, for example, a significant number of students demonstrate limitations in formulating arguments, explaining problem-solving processes, and presenting solutions coherently (Nurjanah et al., 2020; Rohid et al., 2019; Tamur, Ndiung, Kurnila, et al., 2023). These weaknesses not only impact their performance on assessments but also limit their opportunities to engage in meaningful discussions and collaborative problem-solving (Planas et al., 2025; Tamur et al., 2021; Tamur, Weinhandl, et al., 2022). This situation highlights the urgent need for innovative learning approaches that can bridge the gap between mathematical understanding and communication skills.

One promising direction is the integration of digital technology in mathematics learning (Juandi et al., 2021, 2023; Nurjanah et al., 2020; Tamur, Weinhandl, et al., 2022; Tamur, Juandi, et al., 2023; Tamur, Ndiung, Weinhandl, et al., 2023). Among various technological devices, Augmented Reality (AR) has received considerable attention due to its ability to combine virtual objects with real environments, thus creating immersive and interactive learning experiences (Nasongkhla et al., 2019; Tamur, 2023; Tamur et al., 2024, 2025; Zhang & Yao, 2025). The application of AR in mathematics education has been shown to improve students' conceptual understanding, motivation, and engagement (Gusteti et al., 2025; Jampel & Antara, 2025). However, its contribution to improving communication skills is still rarely explored, especially in learning contexts that are still dominated by traditional approaches.

In line with this, the application of ethnomathematics offers a culturally responsive learning approach (Deda, Disnawati, et al., 2024; Deda, Rosa, et al., 2024; Tamur, Pantaleon, et al., 2022). Ethnomathematics recognizes the existence of mathematical practices embedded in local traditions, crafts, and community activities (Prahmana et al., 2021; Widada et al., 2019). By connecting mathematics to students' cultural backgrounds, ethnomathematics encourages contextual understanding and strengthens identity, making mathematics feel more meaningful and less abstract (Supriyadi et al., 2024). Furthermore, ethnomathematics-based tasks often require students to describe, explain, and justify their reasoning (Wulandari et al., 2024), which naturally supports the development of communication skills.

Although AR and ethnomathematics have been extensively researched separately, studies combining these two approaches are still very limited. AR provides technological innovation that can increase engagement (Pérez et al., 2018; Umbara et al., 2021; Yildiz, 2022), while ethnomathematics provides cultural relevance that enriches meaning (Deda, Disnawati, et al., 2024; Deda, Rosa, et al., 2024). When combined, these two approaches have the potential to create a powerful synergy in improving both understanding and communication skills. However, empirical evidence on this integration, particularly at the secondary education level in developing countries, remains scarce.

In Indonesia, efforts to improve the quality of mathematics education have often emphasized curriculum reform and teacher training, but the adoption of technology and culture-based pedagogies remains uneven. Schools in rural areas, such as in East Nusa Tenggara, often face challenges such as limited resources, teacher preparedness, and low student interest in mathematics (Majir et al., 2021; Rahiem, 2020; Widiastuti, 2025). The introduction of innovative models that combine AR and ethnomathematics could be a viable solution, making mathematics learning not only more engaging but also more relevant to students' lives.

Furthermore, mathematical communication skills cannot be viewed as a stand-alone competency, but rather as an essential component of 21st-century skills (Rohid et al., 2019). Effective communication fosters collaboration, critical thinking, and creativity skills that are highly sought after in the global workplace (Kaya et al., 2025). By practicing communication in mathematical contexts, students develop habits of clearly articulating ideas, actively listening, and engaging in constructive dialogue (Kusumah, 2020). Therefore, any innovation that can significantly improve mathematical communication skills deserves serious attention from both researchers and educational practitioners.

Based on the description, this study focuses on the effect of Augmented Reality integration with ethnomathematics-based learning on students' mathematical communication skills. This study attempts to fill the gap in empirical evidence through an experimental study in one of the junior high schools in Ruteng City, Indonesia. The results of the study are expected to contribute not only to the literature on mathematics education and technology integration, but also to culturally responsive pedagogical practices in various contexts. In addition, this study provides insights for the exploration of innovative models that combine technological advances with cultural wisdom to achieve more holistic learning outcomes.

B. METHODS

1. Research Design

This study used an experimental design to test the effect of Augmented Reality (Ethno-AR)-based ethnomathematics learning on students' mathematical communication skills (MCA). The study was conducted in September 2024 at SMP Negeri 6 Langke Rembong, Ruteng, Indonesia. Class VIIA was designated as the experimental class receiving AR-based learning and ethnomathematics, while class VIIC served as the comparison class receiving conventional learning. The research design used was a post-test only control group design to measure differences in students' communication skills after the treatment was administered (Ferráns et al., 2022). This design was chosen because it minimizes the influence of students' prior knowledge so that the impact of the treatment can be measured more objectively. The following is the experimental design scheme used:

Tabel 1. Study Design

Group	Treatment	Posttest
Experimental	Etno-AR	Final Test
Control	Conventional Methods	Final Test

2. Participants and Instruments

This study involved students of the 7th grade program at SMP Negeri 6 Langke Rembong Ruteng in Indonesia as the population. A total of 60 students were randomly selected from eight existing classes with 30 students each divided into experimental and control classes. This random selection technique provided an equal opportunity for all members of the population to be sampled, while strengthening the external validity of the study (Gusteti et al., 2025). The research instrument consisted of five mathematical communication test questions designed to measure students' ability to express ideas, explain problem-solving processes, and present solutions coherently. The instrument was validated by mathematics education experts and

tested for reliability before use. Each question item required a written explanation and structured reasoning, allowing for a comprehensive assessment of mathematical communication. Student answer scores were determined using a predetermined assessment rubric to maintain consistency and objectivity.

3. Data Collection Procedures

Data collection was conducted systematically throughout the treatment period. Students in the experimental class received instruction using an AR application that presented visualizations of ethnomathematical concepts derived from cultural artifacts and local practices of the Manggarai region and the broader local wisdom of East Nusa Tenggara, Indonesia. In contrast, students in the control class received conventional instruction through lectures and textbook-based exercises. Prior to implementation, the mathematical communication test instrument consisting of five items was subjected to content validation through expert judgment by mathematics education specialists to ensure its alignment with learning objectives and construct relevance. Empirical validity testing indicated that all test items met acceptable validity criteria. In addition, reliability analysis demonstrated satisfactory internal consistency, indicating that the instrument consistently measured students' mathematical communication skills.

4. Data analysis

The data obtained were analyzed using SPSS software and Comprehensive Meta-Analysis (CMA) to test the statistical significance and magnitude of the treatment effect. The analysis was conducted using parametric statistical techniques because the data met the assumptions of normality and homogeneity of variance. The test used was an independent samples t-test to compare post-test scores between the experimental and comparison classes. Before conducting the t-test, a statistical assumption test was first conducted to ensure the suitability of the analysis method. The results of the Shapiro-Wilk test showed that the data in both groups were normally distributed, while the Levene test confirmed that the variance between groups was homogeneous. Thus, the requirements of parametric analysis were met and the use of the t-test was considered valid. This condition ensures that the research conclusions have a valid and reliable analytical basis. This strict assumption test also increases the credibility of the reported research results. In addition, the effect size calculation was performed with the help of CMA to determine the practical significance of the AR-based treatment and ethnomathematics. The Hedges formula is Hedges' g = (M1 - M2) / SD_pooled M1 is the mean of the ethno-AR group; M2 is the mean of the control group; and SD_pooled is the combined standard deviation of both classes. The classification of effect sizes uses Cohen et al. (2018) categories, namely small ($g = 0.2$), medium ($g = 0.5$), and large ($g \geq 0.8$). The combination of analysis with SPSS and CMA provides methodological strength because the research results are based not only on hypothesis testing but also on the magnitude of the effect.

C. RESULT AND DISCUSSION

1. Research result

The main objective of this study was to analyze the impact of ethno-AR implementation on MCA. In this study, MCA was characterized by the ability to express ideas, explain problem-solving processes, and present solutions coherently, as seen in the learning process using ethno-AR. The results of the analysis and statistical description of the final test data are presented in Table 2.

Table 2. MCA Statistical Description

Experimental Class				Control Class		
Ideal Score	N	$\bar{x}$	S_d	N	$\bar{x}$	S_d
20	24	19.89	5.64	24	14.22	7.84

Based on Table 2, it can be seen that the average MCA in the ethno-AR class was higher than in the conventional class. Next, a prerequisite analysis test was conducted to ensure the use of the t-test in analyzing the mean difference between the two groups so that it could be used to estimate the population. Table 3 presents the results of the data normality test.

Table 3. Results of the MCA data normality test

Class	Shapiro-Wilk		Interpretation
	Df	Sig	
Etno-AR	23	0.36	Normal distribution
Control	23	0.78	Normal distribution

Table 3 indicates that both samples are normally distributed (sig > 0.05). This condition indicates that most of the data is concentrated around the mean value with a balanced distribution to the left and right. Thus, the assumption of normality is met, allowing parametric statistical tests to be used appropriately to analyze the differences between the two groups. Furthermore, to determine whether the t-test or t'-test is used, a homogeneity test of variance was performed on both samples. Table 4 presents the results of the homogeneity analysis.

Table 4. Results of the MCA data variance homogeneity test

Statistic Levene	Sig.
2.84	0.76

Based on observations in Table 4, it can be seen that the variance of the ethno-AR and conventional classes is homogeneous. This means that the level of diversity or distribution of data in both groups is relatively the same. This condition indicates that the differences in learning outcomes between students in both classes are in a comparable range. Thus, the assumption of homogeneity of variance is met, allowing for a more accurate comparison between the two groups using parametric statistical tests, namely the t-test. Table 5 shows the results of the t-test.

Table 5. Results of MCA Data Difference Analysis

Sig. (2-tailed)	Interpretation
0.01	Ho rejected

Table 5 shows that H0 is rejected, meaning that students' MCA in the ethno-AR class and conventional classes are not the same. This finding confirms that the Augmented Reality-based learning approach combined with ethnomathematics produces significant differences compared to conventional learning. In other words, this innovative intervention is capable of providing a real advantage in developing students' MCA. The rejection of H0 also indicates that students' MCA develops more when they learn through cultural context and interactive visual technology. This strengthens the validity of implementing ethno-AR as an effective and relevant learning strategy in the classroom.

In addition to the t-test, an effect size analysis was conducted using CMA software. Based on Hedges' formula, the effect size value for implementing ethno-AR was 0.81 [CL: 0.24-1.39]. Based on Cohen's classification, this value is accepted as a large effect size, indicating a strong impact of the treatment. This large effect size demonstrates that the integration of AR and ethnomathematics is not only statistically significant but also practically meaningful. In other words, this learning strategy makes a significant contribution to improving students' mathematical communication skills. This success is proof that technology-based and culture-based approaches can work synergistically.

2. Discussion

Overall, this study shows that the use of ethnomathematics-based AR has a significant positive impact on junior high school students' MCA. Students in the experimental class demonstrated improved mathematical argumentation, explanation of solutions, and presentation of ideas. The findings of this study are consistent with previous research highlighting the potential of technology-based learning in improving students' mathematical skills (Juandi et al., 2021, 2023; Nurjanah et al., 2020; Tamur, Weinhandl, et al., 2022; Tamur, Juandi, et al., 2023; Tamur, Ndiung, Weinhandl, et al., 2023; Tamur et al., 2025). Several studies have shown that AR enhances engagement, visualization, and conceptual understanding, which indirectly supports communication skills (Kaliyaperumal, 2020; Osadchyi et al., 2021; Zhengtao & Hidayat, 2025). Similarly, research on ethnomathematics has demonstrated its effectiveness in making mathematics more contextual and meaningful for students (Deda, Disnawati, et al., 2024; Deda, Rosa, et al., 2024; Maharbid et al., 2025; Nuryadi et al., 2023; Wulandari et al., 2024). By combining these two approaches, this study extends previous findings and provides empirical evidence of their combined impact on mathematical communication. This contribution fills an important gap in the literature where AR and ethnomathematics have rarely been studied together.

The effectiveness of AR and ethnomathematics integration lies in the balance between technological stimulation and cultural relevance. AR applications provide students with visual and interactive experiences that reduce the abstraction of mathematical concepts (Jampel & Antara, 2025; Pasaribu et al., 2024; Richardo et al., 2023), thus having a great potential to support students' MCA. At the same time, ethnomathematics connects mathematics with local culture, encouraging students to explain solutions in ways that align with their lived

experiences. This combination motivates students not only to solve problems but also to articulate their reasoning clearly. As a result, the synergy between technology and culture supports deeper understanding and improved communication.

The results of this study have important implications for mathematics teaching and learning practices. Teachers are encouraged to adopt innovative approaches that integrate digital tools with culturally grounded content (Dewi et al., 2024; Muwahiddah et al., 2021; Nugroho et al., 2024; Pramulia et al., 2025). Such practices can bridge the gap between modern pedagogy and local wisdom, making mathematics more accessible and engaging for students. Furthermore, improving students' MCA through this integration equips them with essential competencies for collaboration and critical thinking. Therefore, the application of ethno-AR in classroom practice can be considered a sustainable and transformative innovation.

Beyond practical applications, this research also opens new directions for future research. While the current study focuses on mathematical communication, further research could explore other competencies such as problem-solving, reasoning, or creativity. Researchers could also examine the long-term effects of integrating AR and ethnomathematics across different educational levels and subjects. Comparative studies in urban and rural contexts could provide deeper insights into the scalability of this approach. Overall, this study contributes to the growing body of knowledge on innovative mathematics education and lays the foundation for future advancements in technology- and culture-based pedagogy.

D. CONCLUSION AND SUGGESTIONS

This study demonstrates that the integration of Augmented Reality (AR) and ethnomathematics-based learning has a significant positive impact on students' mathematical communication skills. Theoretically, this research contributes to the discourse on technology-enhanced mathematics education by advancing a culturally integrated learning framework, in which AR serves as a cognitive and visual mediator for abstract mathematical concepts, while ethnomathematics provides contextual and cultural grounding for meaning-making. The findings reinforce the view that effective mathematical communication is strengthened through the synergy of digital technology and culturally responsive pedagogy, thereby extending existing models of innovative mathematics instruction.

Practically, the results suggest that teachers can enhance students' mathematical communication by designing learning activities that integrate AR-based visualizations with culturally relevant mathematical contexts and by encouraging structured oral and written mathematical discourse. Schools and policymakers should support this approach through targeted professional development, access to appropriate AR technologies, and curriculum policies that promote culturally responsive innovation. However, this study is limited by its relatively small sample size, single-school setting, and short intervention duration, which may restrict the generalizability of the findings. Future research is therefore recommended to involve larger and more diverse populations, employ longitudinal designs, and examine the impact of AR and ethnomathematics integration on other competencies such as problem-solving, reasoning, and creativity across varied educational contexts.

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