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Exploring ethnomathematics and the project-based learning model to enhance students' critical thinking skills

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Abstract The significance of mathematics education in fostering students' critical thinking has been widely acknowledged. However, teaching abstract mathematical concepts such as geometry remains a persistent challenge, particularly when these concepts are disconnected from students' real-life experiences. To address this issue, the present study investigates the integration of ethnomathematics and Project-Based Learning (PjBL) as an innovative pedagogical framework for enhancing students' critical thinking and engagement in geometry learning. This study aims to examine the effectiveness of combining ethnomathematics and PjBL in improving students' understanding and application of geometric concepts within culturally relevant contexts. Employing a mixed-methods design, the research collected both quantitative and qualitative data through pretest-posttest assessments and semi-structured interviews with students and teachers. The findings reveal that students exposed to the integrated ethnomathematics-PjBL approach demonstrated significant improvements in critical thinking skills and conceptual understanding. The experimental group achieved a 13.96% increase in posttest scores, compared to only 3.65% in the control group taught using conventional methods. These results indicate that connecting geometry instruction with local cultural elements can make learning more meaningful, engaging, and contextually grounded. This study contributes to the existing body of literature by providing empirical evidence from an understudied educational context, demonstrating how cultural integration can strengthen students' comprehension of abstract mathematical ideas. Moreover, the findings suggest that embedding cultural relevance in mathematics education not only enhances critical thinking and problem-solving skills but also promotes sustained student engagement. Future research should address challenges related to time management and material preparation while extending the application of these approaches across diverse educational settings.

Keywords: mathematics education, contextual learning, cultural integration, collaborative learning, student engagement

1. Introduction

Mathematics education holds a crucial role in equipping students to navigate the complexities of the modern world (Cirneanu & Moldoveanu, 2024; Teoh et al., 2024). Geometry, as one of its core branches, is often perceived as difficult by learners due to the demand for spatial visualization and the abstract nature of its concepts, which might appear detached from everyday experiences (Prahmana & D'Ambrosio, 2020). To address this challenge, it is essential to adopt approaches that make geometric concepts more relatable and meaningful (Kyeremeh et al., 2023). Two promising strategies in this regard are ethnomathematics and Project-Based Learning (PjBL), both of which offer rich cultural context and encourage active student engagement in learning.

To help students make personal connections between mathematical ideas and their own cultural experiences, ethnomathematics incorporates aspects of local culture into mathematics education (Ascher & Ascher, 1986; Pais, 2011). This connection not only enhances relevance but also increases interest and motivation. This study incorporates cultural elements including the traditional Bima house (Uma Lengge), the woven fabric motif Tembe Nggoli, and the traditional game Mpa'a Gopa are utilized. Middle school pupils' grasp of mathematics may be greatly enhanced with the use of ethnomathematics-based modules, according to research by Supriyadi et al., (2024). Despite its benefits, the application of ethnomathematics in geometry remains limited (Andang et al., 2025), indicating a gap that warrants further exploration.

Project-Based Learning (PjBL), on the other hand, is a student-centered pedagogy that engages learners in real-world projects (Satriawan et al., 2025), requiring them to apply their knowledge to solve problems collaboratively. Widely implemented in science and mathematics education, PjBL has proven effective in fostering critical thinking, problem-solving skill, and teamwork. Johnsen et al. (2024) and Wang et al. (2025) demonstrate that PjBL can motivate students to actively

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engage with mathematical theories and connect them to practical applications. Nonetheless, while PjBL is well-established in mathematics instruction, its use within geometry, especially when integrated with cultural context, remains underexplored.

Although both approaches have demonstrated individual success, the integration of ethnomathematics and PjBL in geometry education has rarely been studied. Existing literature often focuses either on ethnomathematics in general mathematics or on PjBL without incorporating cultural dimensions. This study seeks to address that gap by investigating how the integration of ethnomathematics and PjBL in geometry instruction can enhance students' critical thinking skills. By combining cultural relevance through ethnomathematics with real-world engagement via PjBL, this research aims to provide a more meaningful and effective approach to teaching geometry.

Previous studies support the potential of this integration. Bennett, (2014); Wager, (2012) found that embedding cultural elements in mathematics enriches the learning experience and increases student participation. Similarly, Waluya et al. (2022) highlighted how e-modules centered on culture might help students develop their critical thinking abilities. However, literature focusing on the application of these methods within geometry, particularly in project-based formats, is still limited.

Moreover, PjBL has been extensively applied in STEM education to encourage critical and creative problem-solving (Hanafi et al., 2025). Studies by Arrieta-Cohen et al. (2024), Listiyani et al. (2025), and Wang et al., (2025) underscore PjBL's role in promoting student engagement and understanding, linking mathematical knowledge to real-life contexts. It also enhances collaborative and communication skills, which are essential in today's workforce (Johnsen et al., 2024). Still, the use of PjBL in geometry that also embraces local cultural content, as attempted by (Danlami et al., 2025; Hanafi et al., 2025), has yet to gain widespread implementation.

The research gap lies in the limited studies that explore the combined implementation of ethnomathematics and PjBL within geometry education and how such integration can holistically develop students' critical thinking. Earlier research has predominantly examined these approaches in isolation or within the broader scope of general mathematics education, often neglecting the integration of local cultural factors. This research intends to fill that void by focusing specifically on the synergy between these pedagogies in geometry.

The novelty of this study lies in merging two educational strategies, ethnomathematics and PjBL, that are typically addressed separately. By exploring geometry education that incorporates local cultural elements into project-based tasks, this approach not only teaches formulas and theorems but also builds a stronger connection between students and their cultural identity, thereby enhancing engagement and understanding (Arrieta-Cohen et al., 2024; Danlami et al., 2025; Hanafi et al., 2025; and Pais, 2011). The urgency of this study is grounded in the need for mathematics instruction, particularly in geometry, to be more contextual and culturally relevant. Considering Indonesia's cultural diversity, integrating local cultural values into math education can enhance student motivation and impart deeper meaning (Hidayati & Prahmana, 2022). Furthermore, this study aims to contribute an innovative, inclusive pedagogical model that can be adapted across diverse cultural settings. The goal of incorporating ethnomathematics into Project-Based Learning (PjBL) is to create a more culturally inclusive mathematics curriculum by getting students more invested in their own learning and helping them become better thinkers and problem solvers.

2. Materials and Methods

This study takes a mixed-method approach, combining qualitative and quantitative data, to evaluate how well a Project-Based Learning (PjBL) model, in conjunction with ethnomathematics-based digital learning materials, improves junior high school students' critical thinking abilities (Foroudi & Foroudi, 2023). This approach was applied as it allows the researcher to achieve a comprehensive understanding of the phenomenon by utilizing the strengths of both types of data (Creswell & Clark, 2017; McKim, 2017). The research design employed is an exploratory sequential design (Doyle et al., 2009; Hidalgo et al., 2020), in which the first step is to gather qualitative information to better understand how ethnomathematics and PjBL are put into practice, and then the second step is to gather quantitative data to see how much improve students' ability to think critically.

The research population comprised eighth-grade students at SMPN 1 Kota Bima, distributed across 11 classes. A purposive sampling technique was employed to select the sample, designating Class VIIIA as the experimental group, which received ethnomathematics-based teaching materials integrated with Project-Based Learning (PjBL), and Class VIIIB as the control group, which received conventional instruction. The number of selected participants was 50 students. This sampling strategy was implemented to ensure that participants met the predetermined criteria for the intervention and assessment process, namely having mastered prerequisite content and demonstrating sustained engagement throughout the instructional sequence. The approach was chosen to generate data that were contextually grounded and analytically rich rather than intended for broad population generalization (Creswell & Creswell, 2017; Palinkas et al., 2015). Furthermore, three mathematics teachers were engaged as supporting informants to provide additional perspectives on the implementation of ethnomathematics-based learning and PjBL.

From an ethical standpoint, participant confidentiality was safeguarded through anonymized coding procedures, and informed consent served as the basis for voluntary participation. Participants were permitted to withdraw at any stage without academic penalty. All data collection activities were conducted following official approval from the school and in accordance with established ethical guidelines for educational research (Race & Vidal-Hall, 2019).

Data were collected using multiple instruments. A Teacher and Student Needs Survey assessed participants' readiness to use ethnomathematics-based digital materials integrated with Project-Based Learning (PjBL), including technology use, integration of local cultural knowledge, PjBL implementation, and perceptions of students' critical thinking. In-depth interviews with mathematics teachers provided qualitative insights into their experiences and challenges in implementing these materials. The critical thinking test was developed based on the following indicators: interpretation, analysis, evaluation, inference, and explanation (Facione, 2011). Content validity was confirmed through expert judgment by an ethnomathematics specialist, a mathematics education lecturer, and a mathematics teacher, with items considered acceptable if Aiken's V ≥ 0.80. The instrument was pilot-tested on a class outside the research sample to assess reliability using Cronbach's Alpha (≥ 0.70), with items that did not meet the criteria revised or replaced. Validation results indicated that the instrument was both valid and reliable for measuring students' critical thinking skills.

The developed learning materials will be validated by subject matter experts, media specialists, and language experts to ensure the appropriateness of content, media, and language (Waluya et al., 2022). After validation, a pilot test was conducted in class, where both students and teachers evaluated the practicality of the materials through a questionnaire. The Practicality of Learning Materials Survey assess whether the materials are user-friendly for both teachers and students, including aspects such as appearance, time appropriateness, interactivity, and alignment with the PjBL and ethnomathematics models (Han et al., 2016).

To measure improvements in students' critical thinking skill, a pretest was conducted before the learning begins, followed by a posttest after the lesson was completed. The questions were designed to focus on geometry concepts linked to local culture to measure how this approach enhances students' understanding and critical thinking abilities (İbili et al., 2020; Siregar, 2024). Analysis will be conducted on the quantitative data obtained from the tests and surveys using descriptive and inferential statistics (Gundry & Deterding, 2019; Kelley-Quon, 2018; Statistics, 2013). To compare the experimental and control groups' post- and pre-test scores, a paired t-test was used. Furthermore, to find out whether students' critical thinking skills significantly improved, an independent t-test was used to evaluate the learning results between two groups (Erdogan, 2019; Hasanah & Malik, 2020; Yuan et al., 2008). Thematic analysis was used to discover commonalities and differences in the learning experiences of instructors and students using interviews and questionnaires collecting qualitative data (Corry et al., 2014; Yukhymenko et al., 2014).

At the end of the course, students and instructors will fill out surveys on their experiences using ethnomathematics-based learning materials and PjBL. These surveys will serve as evaluation tools for the course. In this activity, students reflected on how the learning experience enhanced their critical thinking skills, while instructors discussed the obstacles encountered and the effects of the teaching approaches on students' motivation and capacity for critical thinking (Creswell & Clark, 2017; Migiro & Magangi, 2011). Data reduction, data presentation, conclusion drawing, and verification were all phases of the qualitative data analysis that adhered to the methodology put out by Miles and Huberman (Onwuegbuzie & Weinbaum, 2016). This study adhered to the relevant ethical guidelines, ensuring respondent confidentiality and voluntary participation.

3. Results and Discussion

3.1. Description of Data on Student Learning Needs and Teacher Teaching Needs

This section presents data obtained from the survey designed to identify student learning needs and teacher teaching needs. The student survey was completed by 50 students and provides insights into their interests and engagement in learning mathematics. Topics covered by the survey questions included students' perspectives on the relevance of mathematics in daily life, the role of local culture in mathematics education, and the ways in which project-based learning may enhance their understanding of the subject. The data reveals how much students feel that mathematical concepts would be easier to understand when taught using the PjBL model, particularly when linked to elements of their local culture, such as traditional fabric patterns, local architecture, or traditional games containing geometric elements. The results of the analysis of student needs are shown in Figure 1.

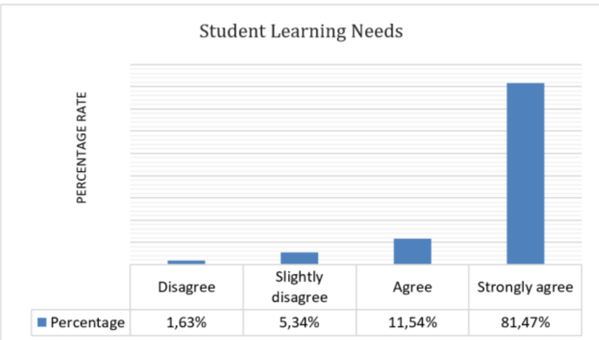

Figure 1 Graph of Student Learning Needs Analysis Results.

The survey results indicate that the majority of students (81.47%) strongly agree with the use of ethnomathematics and the PjBL model in mathematics education. This reflects a high level of interest and motivation among students to learn mathematics by connecting concepts to their local culture, such as fabric patterns, the traditional architecture of Uma Lengge, and local games. Only a small percentage of students (1.63%) express disagreement, but overall, the majority demonstrated readiness for more contextual, project-based learning that focuses on ethnomathematics. These findings provide a solid foundation for integrating local culture and PjBL into mathematics education.

The teacheranalysis survey was also conducted to investigate educators' viewpoints on incorporating technology and digital learning resources into mathematics teaching, gather their opinions on applying the PjBL model in mathematics instruction and identify the difficulties encountered when integrating local culture into the curriculum. The findings of this analysis are presented in Figure 2.

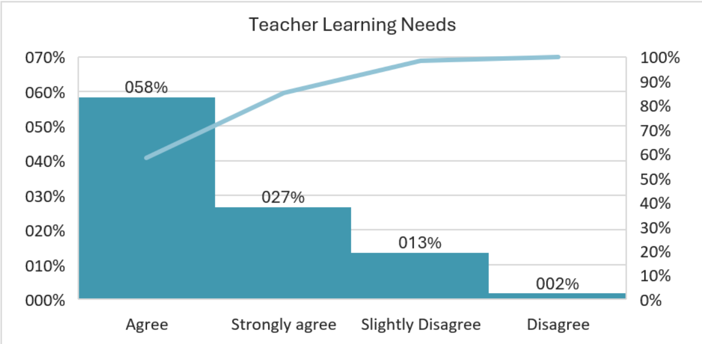

Figure 2 Graph of Teacher Teaching Needs Analysis Results.

The data from the teacher teaching needs survey indicate that the majority of teachers are prepared to implement lessons using ethnomathematics-based digital materials integrated with the Project-Based Learning (PjBL) model. Most teachers (58.33%) agree, and 26.66% strongly agree that these three elements are crucial for improving mathematics education. Only 13.33% disagree to some extent, and 1.67% strongly disagree. This data reflects that most teachers are ready to apply these approaches, although some still feel that they need further support.

Interviews with teachers also confirm their readiness to use ethnomathematics-based digital materials combined with PjBL. Teachers expressed that this approach could increase student engagement and help them better understand mathematical concepts linked to local culture. Math classes that include local culture are more relevant and engaging for kids, according to many instructors. Nevertheless, they were cognizant of the fact that constraints such as time and money may make it difficult to put these strategies into action.

The findings from the needs analysis conducted with both the student and teacher indicate a strong readiness to implement lessons that incorporate ethnomathematics-based digital materials alongside the Project-Based Learning PjBL. Students exhibit high enthusiasm for learning mathematics that connects local culture with mathematical concepts. At the same time, teachers acknowledge the significance of using technology and project-based approaches to improve student engagement and comprehension. The integration of these three elements offers several benefits, such as providing a more relevant and meaningful context, enhancing conceptual understanding through hands-on experiences, and promoting the development of critical thinking and collaboration skills through group-based projects.

3.2. Integration of Ethnomathematics and the PjBL Model in Geometry Education

The traditional Uma Lengge house in Bima contains geometric elements closely related to ethnomathematics, which incorporate mathematical concepts with local culture. The triangular-shaped roof reflects the principles of angles and symmetry, while the arrangement of columns and the rectangular base of the house represent ratios and proportions. Through the approach of ethnomathematics, this traditional house can serve as an effective learning tool to understand geometric concepts, linking mathematical theory to real-world shapes in the local cultural context, thereby offering students a more meaningful and comprehensive understanding.

Figure 3 illustrates student engagement in a learning activity that combines the Project-Based Learning (PjBL) model with ethnomathematics. This activity involves applying geometric concepts to the Uma Lengge Traditional House projects that reflect local culture, with the goal of making mathematics education more contextual and meaningful.

The first image shows students' activity in building a miniatur model of the Uma Lengge traditional house, where they apply geometric concepts such as triangles and rectangles to the roof and column structures. The second image shows students measuring and analyzing the geometric elements of the traditional house, such as angle and side length measurements, which are then connected to mathematical problems. The third image shows students presenting their project results in groups, demonstrating the application of teamwork and communication in solving mathematical problems relevant to their culture.

Figure 3 Student Project Activity: Creating a Traditional House.

The projects challenge students to observe and measure geometric elements on the triangular roof and rectangular structure, and teaching concepts like angles, lines, symmetry, and ratios. The activities also give students the opportunity to apply their understanding of geometry in a cultural context, linking mathematical theory to real-world applications while developing critical thinking and collaboration skills.

The Tembe Nggoli weaving motif from Bima is an example of a cultural value rich in geometric elements that can be used in ethnomathematics education. The patterns, which include triangles, rectangles, rhombuses, and symmetric and repeating lines, reflect how mathematical elements in Bima's local culture, that can be studied and applied in daily life. In geometry education, this motif serves as an effective medium for connecting mathematical concepts with local wisdom, making it easier for students to understand and apply geometric theory. An example of the Tembe Nggoli weaving motif and the students' activity utilizing it in learning can be seen in Figure 4.

Figure 4 displays various motifs from Tembe Nggoli weaving and student learning activities applied in the context of ethnomathematics in geometry education. The clear geometric patterns, such as triangles, symmetric lines, and repeating patterns on the woven fabric, can be utilized to teach geometric concepts such as symmetry, ratios, angles, and proportions. Through the measurement and analysis of these fabric patterns, students not only learn geometric theory abstractly but also see how these concepts are applied in their daily lives. Connecting cultural objects to mathematics education allows students to understand the relationship between theory and practice, making learning more applicable and significant while enhancing their involvement in the learning process.

Figure 4 Tembe Nggoli Weaving Motif and Student Learning Activity.

Another interesting example of linking mathematics with local culture through ethnomathematics is playing the traditional game Mpa’s Gopa. In this game, students are introduced to geometric shapes such as lines, angles, and symmetric patterns present in the playing area. Geometric shapes like squares and rectangles used in Mpa’a Gopa provide students with the opportunity to see how geometric concepts are applied in real life. By engaging in play, students can understand shapes, sizes, and positions easily through physical interaction, which ultimately enhances their understanding of mathematics.

Other cultural objects, such as the gong and handicrafts, are also highly relevant in the context of ethnomathematics. For example, a traditional gong shaped like a cylinder or cone can be used to teach concepts of volume and surface area in mathematics. Similarly, handicrafts such as baskets, doku, and sarau, which display symmetric and repeating patterns, can be used to teach geometric concepts. Linking these cultural objects to mathematics education provides students with an opportunity to see the connection between theory and reality, making learning more contextual, significant, and connected to their everyday experiences, while also increasing their engagement in the learning process.

3.3. Practicality of Ethnomathematics and PjBL Model in Geometry Education

The teaching materials used in this study were validated by experts in the relevant subject areas, language specialists, and media professionals, who confirmed that the materials are valid for use. The practicality of the teaching materials was then evaluated, and the results are presented in the following graph. This data presents assessments from teachers and students regarding ease of use, alignment with learning time, appeal and interactivity, and alignment with the PjBL model and cultural elements. The results of the practicality analysis of the teaching materials are shown in Figure 5.

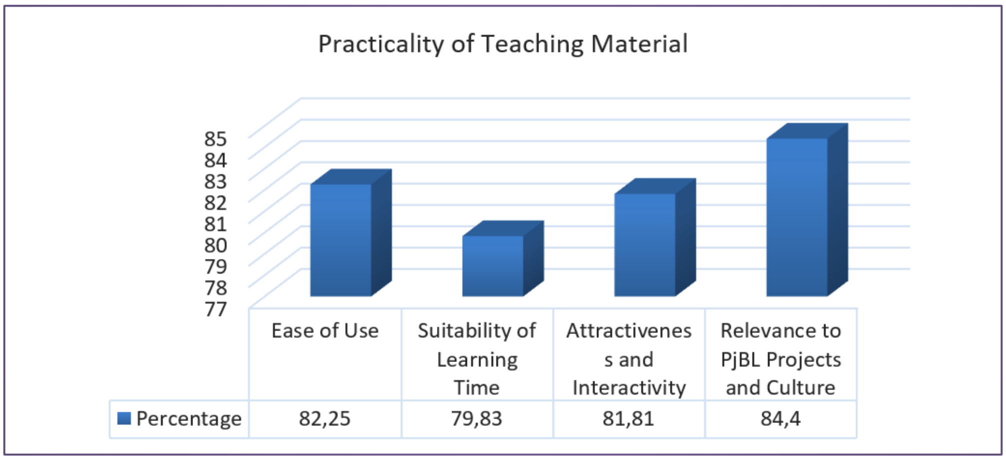

Figure 5 Results of the Teaching Materials Practicality Analysis.

The practicality test of the teaching materials shows that the materials used in PjBL and ethnomathematics-based learning received positive evaluations in various aspects. The ease of use received a score of 82.25%, indicating that both students and teachers found the materials easy to use and access. Additionally, the alignment with learning time received a score of 79.83%, suggesting that the materials are generally suitable for the available learning time, although there were some minor challenges in managing it.

The materials also received a high score for appeal and interactivity, with a score of 81.81%, indicating that the presented content was engaging and able to actively involve students. The highest score was achieved in the alignment with PjBL projects and culture, with a score of 84.4%, indicating that the materials are highly relevant to culture-based learning and projects. Overall, the practicality test results show that the teaching materials are effective in supporting ethnomathematics and PjBL-based learning, improving student engagement, and ensuring that the materials are relevant to their everyday lives.

Qualitative data from the practicality questionnaire indicate that both students and teachers provided in-depth feedback on various aspects, including the ease of use, alignment with learning time, interactivity, and relevance to PjBL and local culture. Data from teachers showed that the ethnomathematics-based materials and PjBL model greatly assist in facilitating the understanding of mathematical concepts related to daily life. Most teachers felt that integrating local culture provided a more meaningful context for students, increasing their engagement in learning. Teachers also noted that the PjBL model provides opportunities for students to work collaboratively, enhancing their critical thinking skills. From the students' perspective, the response to the ethnomathematics-based materials and PjBL was also very positive.

The majority of students expressed high interest and motivation when mathematics learning was connected to their local culture, such as using Tembe Nggoli weaving motif or the Uma Lengge traditional house structure in math learning. Data also showed that PjBL increased student participation in group projects, facilitating their active involvement in learning. Furthermore, students believed that project-based learning allowed them to have a deeper comprehension of the subject and encouraged the growth of their critical thinking abilities.

3.4. Effectiveness of Ethnomathematics and the PjBL Model in Enhancing Students' Critical Thinking Skills

An essay exam with five questions was given to students to evaluate how ethnomathematics and the PjBL paradigm affected their critical thinking abilities. These questions were created to test students' knowledge of geometry in two ways: in the context of their own culture (ethnomathematics) and in projects based on problem-based learning (PjBL). Each question evaluated the students' skills in analysis, interpretation, evaluation, and problem-solving related to the application of geometry in everyday life.

To ensure the experimental group's data was consistent and normal before doing a paired t-test on their pre- and post-test results, we used tests for normalcy and homogeneity. To make sure the data from both the pretest and the posttest were normally distributed, we ran a normality test. To make sure the two groups had identical variances, we ran a homogeneity test. To determine if there was a statistically significant change from the experimental group's pretest to posttest scores, a paired t-test was administered after the data were confirmed to meet the normality and homogeneity assumptions. The results of the paired t-test can be found in Tables 1 and 2. It compares the average scores from the pretest and posttest and uses the p-value to determine whether the difference is significant.

Table 1 Statistical Results of Paired Samples for the Experimental Group.

Experimental Group	Mean	N	Std. Deviation	Std. Error Mean
Pretest experimental	73.3871	31	5.24517	.94206
Posttest experimental	87.3548	31	3.54540	.63677

Table 2 Results of the Paired Test for the Experimental Group.

Group	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pretest-Posttest	13.9677	6.1399	1.102	16.2198	11.71559	-12.66	30	.000

After incorporating ethnomathematics and project-based learning (PjBL), students' critical thinking abilities significantly improved, according to the findings of the paired t-test for the experimental group. An rise of 13.96% was reflected in the average posttest score of 87.35%, compared to an average pretest score of 73.39%. The results show that the students achieved significant gains in geometric concept knowledge and application via the implementation of a teaching technique that blended mathematics with their cultural background. There is a statistically significant difference between the pretest and posttest, as the p-value of 0.000, which is less than 0.05, indicates. Thus, students' critical thinking abilities are improved via the use of ethnomathematics and the PjBL paradigm.

The activities and instruments used enrich their knowledge and enhance their ability to solve problems related to local cultural contexts. Tables 3 and 4 below present the results of the paired t-test for the control group, comparing the average pretest and posttest scores, along with the p-value to evaluate the significance of the difference.

Table 3 Statistical Results of Paired Samples for the Control Group.

Control Group	Mean	N	Std. Deviation	Std. Error Mean
Pretest Control	72.3226	31	4.87433	.87546
Postest Control	75.9677	31	2.16770	.38933

Table 4 Results of the Paired Samples Test for the Control Group

Control Group	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Pretest Control-Postest Control	-3.64516	5.06326	.90939	-5.50238	-1.7879	-4.008	30	000

The control group showed statistically significant improvement between the pre- and post-tests, according to the paired t-test findings. There was a 3.65% shift from the average pretest score of 72.32% to the posttest score of 75.97%. A statistical analysis revealed a significant difference between the control group's pretest and posttest scores (p-value = 0.000). The effect of the traditional teaching method on students' critical thinking skills was less pronounced compared to the experimental group's ethnomathematics and PjBL-based approach, even though there was an improvement; the score change was smaller in the former group.

Tables 5 and 6 below present the results of the independent t-tests for the control and experimental groups, which compare the posttest scores of the two groups after the implementation of the learning strategies. Results from a t-test comparing students' critical thinking abilities after receiving instruction in ethnomathematics and the PjBL model to those after receiving instruction in a more traditional manner are included with descriptive statistics for each group.

Table 5 Results of the Independent Statistical Test.

	Group	N	Mean	Std. Deviation	Std. Error Mean
Results	Posttest for the Control Class	31	75.97	2.168	.389
	Postest for the Experimental Class	31	87.35	3.545	.637

Table 6 Independent Samples Test of Control and Experimental Classes.

	F	Sig.	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Equal variances assumed	5.089	.028	60	.000	-11.387	.746	-12.880	-9.894
Equal variances not assumed			49.679	.000	-11.387	.746	-12.886	-9.888

The experimental and control groups' posttest scores vary significantly, according to the independent t-test findings. Group statistics show that after the intervention, the control group averaged 75.97 on the posttest and had a standard deviation of 2.168, while the experimental group averaged 87.35 and had a standard deviation of 3.545. It seems that the experimental group achieved better results than the control group. There is a statistically significant difference in the posttest scores of both groups, as shown by the t-test for Equality of Means, which yields a p-value of 0.000 (less than 0.05) when equal variances are assumed. The mean difference between the two groups was -11.387, with a 95% confidence interval ranging from -12.880 to -9.894. These findings suggest that the use of ethnomathematics and the PjBL model in the experimental group is considerably more effective in improving students' critical thinking skills compared to the traditional method used in the control group.

3.5. Learning Experience After the Integration of Ethnomathematics and PjBL

The Miles and Huberman approach was used to analyze the interview data collected from the student learning experience questionnaire and the teacher teaching experience questionnaire. The purpose of this analysis was to evaluate the learning experiences of both groups in relation to the integration of ethnomathematics and the Project-Based Learning (PjBL) model. In order to delve further into how both students and instructors see these two methods' use in geometry teaching, this research centers on qualitative data collected from interviews.

3.5.1. Data Reduction

In the first stage, the interview data with students and teachers were analyzed to filter information relevant to the research objectives. Several key themes emerged from these interviews, including student engagement in ethnomathematics and PjBL-based learning, as well as teachers' experiences in implementing both approaches. Students expressed positive responses to ethnomathematics and PjBL-based learning. They felt that linking geometric concepts with local culture, such as the motifs of Tembe Nggoli woven fabrics and the architecture of Uma Lengge, made mathematics learning feel more connected to real life. Students also felt more active and engaged in learning because PjBL encouraged collaboration in culture-based projects. This project-based learning was considered enjoyable and easier to understand, as they could directly observe the application of geometric concepts to familiar cultural objects. The ethnomathematics approach helps connect mathematics with local culture and strengthens students' understanding of mathematical theory through examples they directly experience in their daily lives (Prahmana & D'Ambrosio, 2020). It enables students to build a stronger connection between mathematical knowledge and their personal experiences (Wang et al., 2025). That fact is relevant to the findings of this study.

Incorporating ethnomathematics and PjBL into geometry lessons, according to teachers, helped pupils make connections between mathematical concepts and their own cultural backgrounds. Both of these methods, they believed, helped pupils better grasp the more abstract ideas involved in geometry. Additionally, educators saw that PjBL allowed students to engage in local culture-based projects, which allowed them to think critically and build problem-solving abilities. Nevertheless, a number of educators voiced concerns about the time constraints and increased complexity of project preparation that came with incorporating local culture into each lesson. This is consistent with what was seen in (Payadnya et al., 2024), which stated that although ethnomathematics enriches learning, its integration requires more time and intensive preparation.

3.5.2. Data Presentation

After the data reduction process, the filtered data is presented narratively to depict the main themes that emerged from the interviews. Based on the interviews, the majority of students reported significant benefits from the learning approach that connects mathematics with local culture. They felt more engaged with the material and more motivated to learn geometry when they could relate mathematical concepts to familiar cultural objects. For instance, many students expressed interest in studying symmetry and geometry when they observed geometric patterns in traditional woven fabrics they encountered daily. They also felt more involved in the project due to the opportunity to directly apply mathematical knowledge relevant to their lives. Welsh & Dehler (2013) argue that learning activities which integrate cultural elements can encourage students to be more active and creative in their thinking, as they not only learn concepts theoretically but also see how these concepts are applied in real life. This is reflected in the current study, where students were more engaged in learning and found it easier to understand geometry due to its connection with their local culture.

Teachers indicated that the Project-Based Learning (PjBL) and ethnomathematics approach were very helpful in teaching geometry concepts. They found it easier to connect mathematical theory with local cultural objects that students recognized, such as the Uma Lengge traditional house and the Mpa'a Gopa traditional game. Teachers also felt that project-based learning encouraged more active student involvement and promoted critical thinking. The challenges encountered included a tight timeline for completing culture-based projects and the increased complexity of preparation. Teachers needed to ensure that the projects students engaged in were not only relevant to local culture but also effective in teaching geometry concepts. This aligns with Song et al. (2025) who noted that while PjBL promotes critical thinking, time and resource management remain significant challenges for educators.

3.5.3. Conclusion Drawing and Verification

At this stage, qualitative data from student and teacher interviews were combined with the main findings to verify the alignment between student and teacher experiences regarding the implementation of ethnomathematics and PjBL in geometry learning. Data triangulation from student learning experience questionnaires, teacher teaching experience, and pretest-posttest data was used to validate the findings and ensure the reliability of the results.

Overall, the data from interviews show that both students and teachers experienced positive benefits from the implementation of ethnomathematics and PjBL in geometry learning. Students felt more engaged and connected to the material because this approach linked mathematical concepts to their local cultural context, making learning more meaningful and enjoyable. In addition, teachers found it easier to teach geometry because they could connect mathematical theory with the real world of the students, which in turn helped students understand abstract concepts. However, the challenges faced included limited time to complete culture-based projects and the more complex preparation required to integrate cultural context into mathematics learning. This is in line with (Babalola & Keku, 2024; Ulya et al., 2024), who stated that PjBL and ethnomathematics are effective approaches for enhancing student engagement and understanding of geometry, while also developing the critical thinking skills of the students.

In order to enhance students' critical thinking abilities in geometry instruction, this project explores the integration of ethnomathematics with the Project-Based Learning (PjBL) paradigm. The findings demonstrate that this dual approach significantly enhances learners' comprehension of geometric principles. Students in the experimental group, who were taught using these methods, achieved higher average posttest scores compared to those in the control group exposed to conventional instructional techniques. This suggests that students find ethnomathematics and PjBL more useful because they help them make connections between theoretical ideas and their own real-life experiences, especially those that are culturally specific to their own communities.

The approach that integrates ethnomathematics with Project-Based Learning (PjBL) aligns with the findings of several previous studies, which suggest that connecting mathematical concepts with local culture can deepen understanding and enhance student engagement. Payadnya et al. (2024) argue that ethnomathematics offers students an opportunity to grasp mathematical concepts within their cultural context, thereby increasing the relevance of the learning material. Similarly, Aikenhead (2021) and Patras et al. (2023) highlight that culture-based learning enriches students' understanding of more abstract mathematical concepts. Furthermore, Barak & Yuan (2021) and Song et al. (2025b) assert that project-based learning incorporating cultural elements can boost students' motivation and participation, thus contributing to the development of their critical thinking skills.

Based on the results of the paired t-test, the improvement in students' critical thinking skills in the experimental group was highly significant, with an average increase of 13.96%. This indicates that integrating mathematics with local cultural elements had a stronger impact on students' understanding, particularly in applying geometric concepts. In contrast, the control group exhibited a smaller increase (3.65%), suggesting that conventional methods, while positive, are less effective in enhancing critical thinking compared to culturally grounded and Project-Based Learning (PjBL) approaches. These findings highlight the effectiveness of culturally responsive mathematics instruction and the advantages of PjBL in promoting student engagement and participation (Knuth, 2016; Rehman et al., 2024).

The study further demonstrates that combining ethnomathematics and PjBL not only enhances students' technical skills in geometry but also strengthens critical thinking according to Facione (2011) indicators: interpretation, analysis, evaluation, inference, and explanation. For instance, students were able to interpret local cultural patterns, such as Tembe Nggoli woven motifs and Uma Lengge traditional house structures, in geometric contexts, analyze and evaluate relationships among concepts, draw inferences, and explain problem-solving processes systematically. These results align with prior research indicating that integrating cultural context and project-based learning significantly promotes students' critical thinking and problem-solving skills (Andang et al., 2025; Williamson, 2023). By connecting theory and practice directly, this approach enhances student motivation, participation, and the relevance of mathematics learning.

Furthermore, the findings of this study provide valuable insights into the implementation of ethnomathematics and Project-Based Learning (PjBL) in the context of mathematics education at schools in Bima, particularly at SMPN 1 Kota Bima, which possesses rich local cultural resources that can be leveraged in teaching and learning. This research demonstrates that by linking mathematics with cultural aspects, students can experience more contextual and meaningful learning, which, in turn, enhances their understanding and engagement in the subject. This supports the argument put forward by Bray & Tangney (2016) and Nasir et al. (2008), some argue that students might be more engaged and have a better grasp of mathematical topics when culture is included into mathematics lessons.

This research has some limitations, despite the fact that its findings demonstrate substantial effectiveness in implementing these two techniques. One of the limitations is the limited time available to complete the culture-based projects, as well as the higher complexity in material preparation, which requires the integration of local culture in each project. Several teachers involved in this study also noted that the limited time to complete the culture-based projects was a major challenge. A further caveat is that the findings may not apply to a larger population since this research only used data from one institution. To further understand the impact of ethnomathematics and PjBL on mathematics education, future studies should use bigger and more varied samples (Larasati et al., 2025; and Pertiwi et al., 2025).

Positive comments on using ethnomathematics and PjBL to teach geometry were found in the qualitative data collected from interviews with both students and teachers. Students were more engaged and had an easier time grasping the geometric principles presented when they were able to make connections to their own cultural experiences. Participating in project-based learning allowed students to put their mathematical understanding to use in a way that was more personally meaningful. This is consistent with what research by (Waluya et al., 2022; Tytler et al., 2023), they provide evidence that student engagement and comprehension may be enhanced via the incorporation of cultural elements into mathematical education. Teachers also noted that students were able to practice critical thinking and problem-solving abilities via culturally relevant projects while using project-based learning.

Therefore, this research makes a meaningful contribution to advancing a more contextual and applicable mathematics education for students. The combination of ethnomathematics and PjBL presents a method that not only boosts student engagement in learning mathematics but also helps make abstract concepts more accessible and easier to understand. Although there are challenges in implementing this approach, the study's findings indicate that this culture-based method holds significant promise to improve the quality of mathematics education in schools with varied cultural backgrounds.

4. Conclusions

This study found that the Project-Based Learning (PjBL) paradigm and ethnomathematics may help students improve their geometry critical thinking abilities. The results showed a notable improvement in students' ability to apply geometric concepts when tied to local cultural contexts, with the experimental group achieving a 13.96% increase in posttest scores, compared to just 3.65% in the control group. This demonstrates the effectiveness of combining these two approaches in making learning more relevant and engaging. According to the results, teachers may boost student engagement and critical thinking by including local cultural aspects into mathematics lessons. This study fills a gap in the literature by demonstrating, in an understudied region, how ethnomathematics and PjBL may greatly enhance students' comprehension of abstract mathematical ideas. Future studies should aim to address challenges such as time limitations and material preparation, as well as investigate the broader applicability of these methods across various educational settings. In conclusion, this study offers a viable strategy for increasing student engagement and enhancing learning results in geometry by highlighting the significance of integrating cultural relevance into mathematics teaching.

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5. Declarations

5.1. Ethical considerations

This study was conducted in accordance with ethical standards for research involving human participants. The confidentiality of participants was maintained throughout the research process, and all data were anonymized to safeguard their identities.

5.2. Use of artificial intelligence (AI)

The authors declare that the generative artificial intelligence (AI) tool QuillBot was used exclusively for language editing and/or grammatical improvement. The use of AI did not influence the scientific content, study design, data analysis, data interpretation, results, or conclusions of the manuscript. Full responsibility for the content remains with the authors.

5.3. Conflict of Interest

The authors declare no conflicts of interest.

5.4. Funding

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