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Improving the Process of Understanding the Representation of Spatial Shapes Through the Problem-Based Learning Model Assisted by Ethnomathematics in Junior High School Students

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Abstract

This study examines the comparative improvement in junior high school students' understanding of spatial shape representation through the implementation of the Problem-Based Learning (PBL) model assisted by Ethnomathematics. The study employed a quasi-experimental Non-Equivalent Control Group Design involving 60 seventh-grade students at a junior high school in Bima Regency, consisting of an experimental class (n=30) and a control class (n=30). The intervention was conducted over four weeks through learning activities integrating local Bima cultural contexts, such as Uma Lengge vernacular architecture, into problem-solving and group discussion activities related to spatial geometry concepts. Pretest results indicated relatively comparable initial abilities between the experimental class (M=59.53) and the control class (M=59.00), while posttest results showed higher achievement in the experimental class (M=81.03) compared to the control class (M=69.97). An independent samples t-test yielded $t=4.699$ with $p<0.001$, indicating a statistically significant difference between the two groups. N-Gain analysis showed a moderate improvement in the experimental class (0.557) and a low improvement in the control class (0.272). Furthermore, Cohen's d effect size analysis produced a value of 1.213, indicating a large practical effect. The findings suggest that integrating ethnomathematics within the PBL framework may support students in connecting cultural representations with mathematical concepts and contribute to the development of culturally contextualized mathematics learning in junior high schools.

Keywords: Ethnomathematics; Spatial shapes; Problem-based learning; Spatial representation; Junior high school

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INTRODUCTION

The development of spatial shape representation understanding occupies a central position in contemporary mathematics education, particularly within the framework of geometry learning at the junior high school level. Spatial representation defined as the cognitive capacity to interpret, visualize, and construct two- and three-dimensional geometric forms across multiple representational systems constitutes a fundamental mathematical competency that underpins higher-order reasoning in algebra, calculus, physics, and engineering (Annajmi et al., 2026; Sukestiyarno et al., 2023). The integration of ethnomathematical contexts into geometry instruction has emerged as one of the most theoretically compelling and practically effective strategies for bridging the well-documented gap between students' cultural experience and the abstract demands of formal geometric representation (Palupi et al., 2025; Fatra et al., 2025). Within Indonesian education, where the national curriculum mandates culturally responsive pedagogy yet implementation remains inconsistent, the imperative for evidence-based instructional models that simultaneously develop representational fluency and cultural mathematical literacy has become increasingly urgent. Geometric understanding constitutes approximately 30–35% of the mathematics curriculum at the junior high school level and consistently represents the dimension in which Indonesian students demonstrate the lowest achievement in international and national assessments (Hadi, 2026; Turmuzi et al., 2023)

Internationally, data from PISA 2022 (State, 2022) reveals that Indonesian students rank 69th out of 81 participating countries in mathematical literacy, with spatial reasoning and geometric representation identified as the subdomain exhibiting the most critical deficits only 18% of Indonesian students reached the baseline Level 2 in spatial tasks At the school level, preliminary observations conducted at SMP Negeri 1 Belo revealed that students experienced considerable difficulties in understanding spatial shape representation. The average score obtained from the initial assessment was 45.4, indicating that most students had not yet achieved the expected level of competence in spatial geometry concepts.

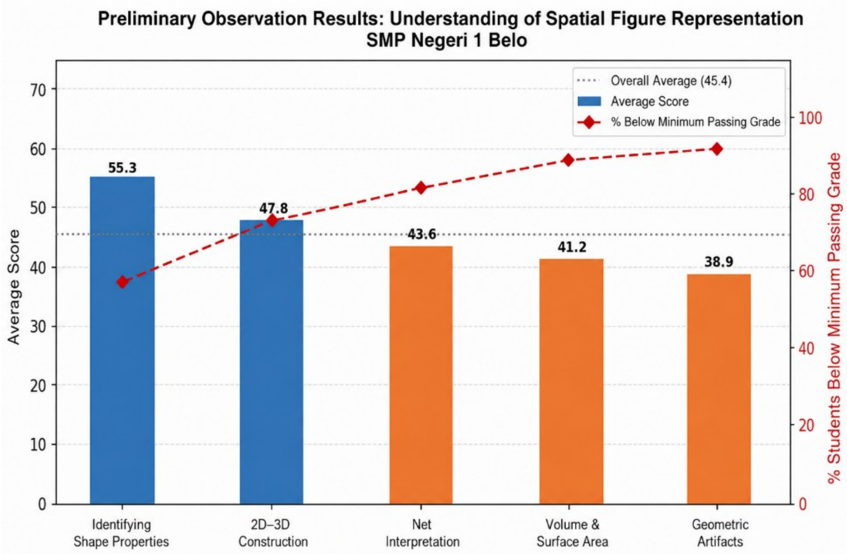

Figure 1. Profile of Understanding of Spatial Figure Representations by Indicator

The Problem-Based Learning (PBL) model assisted by Ethnomathematics constitutes a pedagogically innovative and theoretically grounded solution to the deficits identified above. PBL, as conceptualized by Hmelo-Silver and refined by subsequent researchers (Muhali & Asy'ari, 2026), positions authentic, ill-structured problems as the primary catalyst for learning, requiring students to collaborate, investigate, and construct multi-modal representations in service of problem resolution. Its integration with ethnomathematical contexts specifically the geometric heritage of Bima culture including Uma Lengge traditional architecture (Gunawan & Mugnisjah, 2024; Karyono et al., 2012) and Mbojo decorative carvings (Prayitno & Badu Kusuma, 2021) transforms abstract spatial shapes into culturally meaningful objects of inquiry.

Supporting evidence for this integrated approach is compelling. Mei et al. (2025) demonstrated that problem-solving learning based on ethnomathematics significantly improved creative thinking in elementary students, while Hadi (2026) confirmed the efficacy of ethnomathematics integration in digital geometry learning for junior high students. Annajmi et al. (2026) documented substantial gains in mathematical conceptual understanding through PBL with local cultural contexts in a flipped classroom.

Setiawan & Wiraya (2025) further found that ethnomathematics-nuanced problem-solving tasks effectively revealed variation in students' mathematical ability profiles in junior high school, while Ramadhani et al. (2022) demonstrated through Rasch model analysis that ethnomathematics-based instruments can equitably assess statistical reasoning across diverse demographic backgrounds. At the regional level, Wulandari et al., (2024) affirmed positive educator perspectives toward ethnomathematics integration in South-East Asian mathematics learning, underscoring the cultural receptiveness that makes ethnomathematical approaches particularly viable in the Indonesian context.

Previous studies have reported positive outcomes of ethnomathematics-based learning, Problem-Based Learning, and spatial representation instruction in mathematics education. Nevertheless, these strands of research have largely been examined independently. Limited evidence is available regarding how local cultural artefacts can be systematically integrated into the phases of Problem-Based Learning to support the development of students' spatial shape representation. This gap is particularly evident in junior high school contexts in Eastern Indonesia.

Accordingly, this study contributes to the literature by proposing and empirically evaluating an instructional framework that integrates Problem-Based Learning, Bima cultural artefacts, and spatial shape representation indicators. The framework establishes explicit connections between culturally meaningful objects and the cognitive processes involved in representing, interpreting, and constructing spatial forms, thereby extending current approaches to culturally responsive mathematics instruction. Grounded in this analysis, two research questions guide the investigation: (1) Is there a significant difference in spatial shape representation understanding between students who learn through PBL-Ethnomathematics and those who receive conventional instruction? (2) How large is the effect of the PBL-Ethnomathematics model, as measured by N-Gain and effect size?

METHOD

This study employed a quantitative quasi-experimental approach using a Non-Equivalent Control Group Design. The research was conducted in a junior high school in Kabupaten Bima, where students were organized into three intact parallel classes formed based on the school's administrative placement system. Because the classes were pre-existing and school schedules could not be altered, random assignment of individual students was not feasible. Therefore, two classes were selected through purposive sampling based on comparable academic characteristics obtained from previous semester achievement records. One class was assigned as the experimental group and the other as the control group.

Both groups were taught by the same mathematics teacher to minimize teacher-related effects, and both received equal instructional time, consisting of eight meetings with 2 × 40 minutes per session. The experimental group was taught using a Problem-Based Learning (PBL) model integrated with Bima ethnomathematical contexts, while the control group received conventional instruction, defined as teacher-centered learning dominated by explanation, demonstration, and routine exercises without contextual integration

Before its translation into spatial geometry tasks, the cultural meaning of Uma Lengge warrants brief explanation. Uma Lengge is a traditional two-story stilt house of the Dou Mbojo indigenous community of Bima, functioning simultaneously as a family dwelling and a rice granary. The term itself reflects this duality: "uma" means house, while "lengge" refers to the pursed, crossed form of its roof. Structurally, the building is supported by four main wooden pillars and has a base area of approximately 78 m², with an open ground floor used for receiving guests and an enclosed upper floor used for sleeping and grain storage. The roof is conical and overhangs the upper walls, with its crossed ridge ends carrying symbolic meaning linked to buffalo-horn motifs found in vernacular architecture across the Sumatra region.

This structure offers a naturally occurring geometric composition: a quadrilateral base supported by four corner pillars, suggestive of a rectangular prism for the lower stilt structure, topped by a conical/pyramidal roof form. Because Uma Lengge is a familiar, functionally significant structure within Bima communities rather than an arbitrary decorative object, it provides an authentic entry point for students to reason about three-dimensional shape properties, nets, and volume using a structure whose proportions and function they already understand from daily cultural life.

Other cultural artefacts mentioned in the instructional sequence the granary, woven hat (sapu), Mbojo carving, and Bima textile (tembe) were incorporated as illustrative and narrative contexts within the worksheets (LKPD) to introduce specific geometric sub-topics (nets and symmetry), rather than as physical instructional media. The present study's primary ethnomathematical and hands-on emphasis is therefore placed on Uma Lengge, for which a physical miniature was used as shared instructional media in small-group activities, allowing students to directly measure, unfold, and reconstruct its component geometric shapes. The experimental design structure is presented in Table 1.

Table 1. Quasi-Experimental Non-Equivalent Control Group Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_3	X_2	O_4

Note: X_1 = PBL model assisted by Ethnomathematics; X_2 = Conventional instruction; O_1, O_3 = Pretest; O_2, O_4 = Posttest of spatial shape representation understanding.

Table 2. Population, Sample, and Participant Characteristics

Aspect	Category	Exp. Class (n, %)	Ctrl. Class (n, %)	Total (n, %)
Population	All Grade VII (3 parallel classes)	-	-	93 (100%)
Sample	Selected classes	30 (50.0%)	30 (50.0%)	60 (64.5%)
Gender	Male	14 (46.7%)	15 (50.0%)	29 (48.3%)
	Female	16 (53.3%)	15 (50.0%)	31 (51.7%)
Age (years)	12	9 (30.0%)	10 (33.3%)	19 (31.7%)
	13	16 (53.3%)	15 (50.0%)	31 (51.7%)
	14	5 (16.7%)	5 (16.7%)	10 (16.6%)
Grade Level	Grade VII (Junior High)	30 (100%)	30 (100%)	60 (100%)

Table 3. Data Analysis Framework

No	Analysis Type	Statistical Technique	Parameter	Decision Criterion
1	Instrument Validity	Pearson Product Moment	r-computed	r-computed > r-table (α=5%)
2	Instrument Reliability	Cronbach's Alpha	α coefficient	$\alpha \geq 0.70$
3	Normality Test	Shapiro-Wilk	Sig.	Sig. > 0.05
4	Homogeneity Test	Levene's Test	Sig.	Sig. > 0.05
5	Hypothesis Test	Independent Samples t-test	Sig. (2-tailed)	Sig. < 0.05
6	Learning Gain	Normalized N-Gain	g score	Low $g<0.3$; Moderate $0.3 \leq g<0.7$; High $g \geq 0.7$
7	Effect Size	Cohen's d	d value	Small $d<0.2$; Medium 0.2–0.8; Large >0.8

The intervention was conducted over eight instructional meetings, with each meeting lasting 2 × 40 minutes. Both the experimental and control groups studied the same geometry content related to spatial shapes. The experimental group received Problem-Based Learning (PBL) integrated with ethnomathematical contexts from Bima culture, whereas the control group received conventional instruction.

The PBL implementation followed five phases: (1) problem orientation, (2) organizing students for investigation, (3) guiding individual and group investigations, (4) developing and presenting solutions, and (5) analyzing and evaluating the problem-solving process. Student Worksheets (LKPD) were designed to facilitate each phase of the learning process.

The ethnomathematical component was incorporated through the use of local cultural artifacts, including Uma Lengge traditional houses, Bima granaries, Mbojo carvings, woven hats, and Bima woven fabrics. These artifacts were transformed into mathematical problems involving the identification of geometric properties, construction of spatial representations, interpretation of nets, and calculation of volume and surface area.

For example, the roof structure of Uma Lengge was used to introduce pyramid concepts and spatial properties. Bima granaries were modeled as prisms to explore geometric characteristics and volume calculations. Traditional woven hats were utilized to investigate cone nets and surface structures, while Mbojo carvings and woven fabric motifs were employed to examine symmetry, geometric patterns, and spatial representations.

Students worked collaboratively in groups to analyze cultural artifacts, formulate mathematical representations, solve contextualized problems, and present their findings. At the end of each lesson, students reflected on the relationship between local cultural knowledge and mathematical concepts. Assessment was conducted through observation of learning activities, completion of LKPD tasks, and pretest-posttest measurements of spatial shape representation understanding.

RESULTS AND DISCUSSION

Validity and Reliability of the Instrument

Instrument validation was performed on all 10 test items using Pearson Product Moment correlation analysis with a pilot sample of 30 students (df=28, r-table=0.361, α=5%). All items demonstrated r-computed values exceeding the critical threshold, ranging from 0.391 to 0.819. The highest validity coefficients were recorded for SSR-5 items (volume and surface area: r=0.812 and r=0.819), indicating strong alignment with the overall spatial representation construct. No item was eliminated, confirming the full 10-item instrument as valid for deployment in the main study.

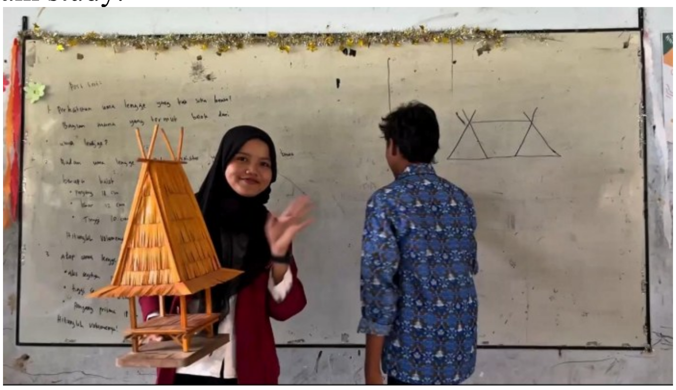

Figure 2. Learning Activities Using the Uma Lengge Ethnomathematics Context in the Experimental Class

The implementation of ethnomathematics-based Problem-Based Learning (PBL) was carried out through five phases: problem orientation, organizing students for investigation, guiding investigation, developing and presenting solutions, and analyzing and evaluating the problem-solving process. During the problem orientation phase, the teacher introduced cultural artifacts from Bima, particularly the Uma Lengge traditional house, traditional granaries, woven hats, Mbojo carvings, and Bima woven fabrics. Students were encouraged to observe these artifacts and identify geometric forms embedded within them. For example, students examined the structure of a miniature Uma Lengge and were asked to determine which parts could be represented as prisms, pyramids, or other three-dimensional shapes. This activity was intended to develop students' ability to identify and interpret geometric properties of spatial objects.

In the organizing phase, students were divided into small groups and provided with student worksheets (LKPD) containing contextual problems based on Bima cultural artifacts. The teacher facilitated group discussions and guided students in formulating mathematical representations of the observed objects. For instance, students were asked to compare the roof and body structures of Uma Lengge and explain their geometric characteristics. Through these activities, students learned to connect cultural objects with formal mathematical concepts.

During the investigation phase, students explored the dimensions, structures, and geometric properties of the cultural artifacts. The teacher guided students in constructing representations of spatial shapes through sketches, diagrams, and geometric models. Traditional granaries were used to investigate prism concepts, while woven hats were utilized to explore the relationship between three-dimensional objects and their corresponding nets. Students were required to draw representations, identify geometric components, and explain relationships among faces, edges, and vertices. These activities targeted students' abilities to construct and interpret spatial representations.

In the developing and presenting solutions phase, students solved contextualized problems related to volume and surface area. For example, students were asked to determine the storage capacity of a traditional granary modeled as a triangular prism and explain the mathematical procedures used to obtain the solution. Students then presented their work to the class and justified their reasoning. This phase encouraged students to communicate mathematical ideas and translate real-world situations into formal mathematical representations.

Finally, during the analyzing and evaluating phase, students reflected on the relationship between local cultural knowledge and mathematical concepts. The teacher presented examples of Mbojo carvings and Bima woven fabric motifs and asked students to identify geometric patterns and symmetry. Students analyzed the mathematical structures embedded within the cultural designs and discussed how geometry is reflected in local cultural practices. Through these activities, students developed a deeper understanding of spatial shape representation while simultaneously appreciating the mathematical values contained in Bima cultural heritage.

Table 4. Instrument Reliability Results

Instrument	Number of Items	Cronbach's Alpha	Reliability Category
Spatial Shape Representation Test	10	0.883	Excellent Reliability

Reliability analysis using Cronbach's Alpha yielded $\alpha=0.883$, substantially exceeding the accepted threshold of 0.70. This value indicates excellent internal consistency, confirming that the 10-item spatial representation test reliably and consistently measures the targeted construct across all five indicators.

Normality and Homogeneity Tests

The Shapiro-Wilk normality test was selected as the appropriate test for samples of $n=30$. Results for the pretest data indicated non-normal distributions in both classes (Experimental Pretest: $W=0.921$, $p=0.028$; Control Pretest: $W=0.923$, $p=0.032$), attributable to heterogeneous entry-level spatial geometry knowledge. Posttest distributions for both groups achieved normality (Experimental Posttest: $W=0.955$, $p=0.236$; Control Posttest: $W=0.958$, $p=0.278$), confirming that posttest scores satisfy the distributional assumptions required for parametric analysis.

Table 5. Shapiro-Wilk Normality Test Results

Group	Data	W Statistic	df	Sig.	Decision
Experimental	Pretest	0.921	30	0.028	Non-normal
	Posttest	0.955	30	0.236	Normal

Group	Data	W Statistic	df	Sig.	Decision
Control	Pretest	0.923	30	0.032	Non-normal
	Posttest	0.958	30	0.278	Normal

Table 6. Levene's Homogeneity of Variance Test Results

	Levene Statistic (F)	df1	df2	Sig.	Decision
Pretest	0.232	1	58	0.632	Homogeneous
Posttest	1.169	1	58	0.284	Homogeneous

Pretest and Posttest Results

Descriptive analysis reveals a pattern of results providing strong evidence for the differential effectiveness of PBL-Ethnomathematics instruction. Prior to the intervention, both groups demonstrated statistically equivalent baseline scores: the experimental class recorded a pretest mean of 59.53 (SD=8.27) and the control class 59.00 (SD=8.33), a non-significant difference of 0.53 points (p=0.808). Following eight sessions of differentiated instruction, posttest scores diverged substantially: the experimental class achieved a mean of 81.03 (SD=10.23), a gain of 21.50 points (+36.1%), while the control class reached 69.97 (SD=7.85), a gain of 10.97 points (+18.6%).

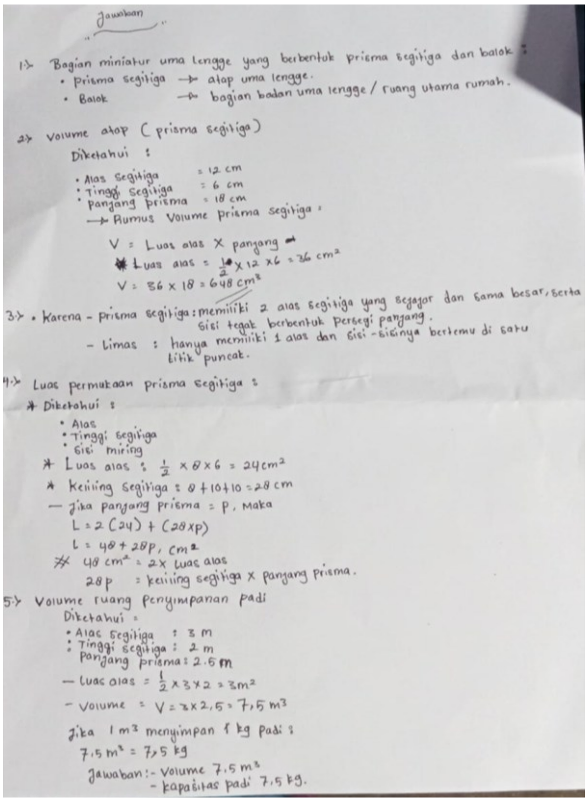
Jawaban
1.> Bagian miniatur uma lengge yang berbentuk prisma segitiga dan balok :
• Prisma segitiga → atap uma lengge.
• Balok → bagian badan uma lengge / ruang utama rumah.
2.> Volume atap (prisma segitiga)
Diketahui :
• Alas segitiga = 12 cm
• Tinggi segitiga = 6 cm
• Panjang prisma = 18 cm
→ Rumus Volume prisma segitiga :
V = Luas alas X panjang
Luas alas = 1/2 x 12 x6 = 36 cm²
V = 36 x 18 = 648 cm³
3.> • Karena - prisma segitiga : memiliki 2 alas segitiga yang sejajar dan sama besar, serta sisi tegak berbentuk persegi panjang.
- Limas : hanya memiliki 1 alas dan sisi-sisinya bertemu di satu titik puncak.
4.> Luas permukaan prisma segitiga :
* Diketahui :
• Alas
• Tinggi segitiga
• Sisi miring
* Luas alas : 1/2 x 8 x 6 = 24 cm²
* Keliling segitiga : 8 + 10 + 10 = 28 cm
— Jika panjang prisma = p, maka
L = 2 (24) + (28 x p)
L = 48 + 28p, cm²
48 cm² = 2x Luas alas
28p = keliling segitiga x panjang prisma.
5.> Volume ruang penyimpanan padi
Diketahui :
• Alas segitiga : 3 m
• Tinggi segitiga : 2 m
• Panjang prisma : 2.5 m
— Luas alas = 1/2 x 3 x 2 = 3m²
- Volume = V = 3 x 2,5 = 7,5 m³
Jika 1 m³ menyimpan 1 kg padi :
7.5 m³ = 7,5 kg
Jawaban : - Volume 7.5 m³
- kapasitas padi 7,5 kg.

Figure 3. Student answer

Figure 3 presents an example of a student’s response from the experimental group after participating in ethnomathematics-based Problem-Based Learning. The student's work demonstrates a high level of spatial shape representation understanding across several indicators.

The student successfully identified the geometric forms embedded in the Uma Lengge model by recognizing the roof as a triangular prism and the main body as a rectangular prism. This indicates the ability to connect real-world cultural artifacts with formal geometric concepts. Furthermore, the student correctly represented the mathematical information provided in the problem and applied the appropriate formula for calculating the volume of a triangular prism. The solution showed accurate determination of the triangular base area and correct substitution into the volume formula, resulting in a correct final answer. This demonstrates the student's ability to translate contextual information into mathematical representations and perform procedural calculations accurately.

The student also explained the differences between prisms and pyramids based on their geometric properties. The explanation showed conceptual understanding, as the student identified that prisms have two congruent and parallel bases, whereas pyramids have a single base with lateral faces meeting at a vertex. This response reflects the ability to interpret and communicate geometric concepts using mathematical language.

In addition, the student correctly formulated the surface area expression of a triangular prism by identifying the area of the bases and the lateral faces. Although the solution remained in algebraic form because the prism length was not specified, the mathematical reasoning and representation process were appropriate.

Finally, the student solved a contextual problem related to the storage capacity of a traditional granary by calculating the volume of the structure and interpreting the result in terms of rice storage capacity. This finding suggests that the student was able to apply geometric concepts to solve authentic problems rooted in local cultural contexts.

Overall, the response indicates that the student achieved a high level of spatial shape representation understanding, including identifying geometric properties, constructing mathematical representations, interpreting geometric relationships, and solving contextualized problems involving cultural artifacts.

Based on the scoring rubric, the student obtained the maximum score on most indicators of spatial shape representation understanding. The response demonstrated proficiency in identifying geometric properties (SSR-1), constructing and interpreting representations (SSR-3 and SSR-4), solving volume and surface area problems (SSR-5), and relating cultural artifacts to geometric concepts (SSR-6). These findings support the quantitative results indicating that students in the experimental group developed stronger spatial shape representation understanding after participating in ethnomathematics-based Problem-Based Learning.

Correlation Analysis

Pearson correlation analysis between pretest and posttest scores was conducted for each class. The experimental class demonstrated a very strong positive correlation ($r=0.905$, $r^2=0.819$, $p<0.001$), indicating that approximately 81.9% of variance in experimental posttest scores is explained by pretest performance consistent with the theoretical proposition that PBL-Ethnomathematics builds systematically on students' existing geometric knowledge structures. The control class also exhibited a strong positive correlation ($r=0.877$, $r^2=0.769$, $p<0.001$), though the slightly lower value indicates marginally less coherent knowledge consolidation.

Table 7. Pearson Correlation: Pretest–Posttest

Group	r (Pearson)	r²	Sig.	Interpretation
Experimental (PBL-Ethnomathematics)	0.905	0.819	<0.001	Very strong, highly significant
Control (Conventional)	0.877	0.769	<0.001	Strong, highly significant

Independent Samples t-test

The independent samples t-test was applied to posttest scores after confirming full parametric assumptions. The test yielded $t=4.699$ with $df=58$ and a two-tailed significance of $p<0.001$ ($p=0.000017$). This result provides overwhelming statistical evidence to reject the null hypothesis (H_0: $\mu_1=\mu_2$), establishing that the posttest mean of the experimental class (81.03) is significantly higher than that of the control class (69.97). The magnitude of $t=4.699$ substantially exceeds the critical value of $t_{0.05}(58)=2.002$.

Table 8. Independent Samples t-test: Posttest Results

Group	Mean	SD	t-statistic	df	Sig. (2-tailed)	H_0 Decision
Experimental (PBL-Ethno)	81.03	10.23	4.699	58	0.000	Rejected
Control (Conventional)	69.97	7.85				

N-Gain and Effect Size Analysis

Normalized N-Gain analysis yielded a mean N-Gain of 0.557 (SD=0.177) for the experimental class placing the cohort in the 'moderate' category ($0.3 \leq g < 0.7$). Category distribution within the experimental class: 6 students (20.0%) achieved high N-Gain ($g \geq 0.7$), 23 students (76.7%) achieved moderate N-Gain, and only 1 student (3.3%) fell in the low category. In contrast, the control class yielded a mean N-Gain of only 0.272 (SD=0.102), firmly in the 'low' category, with 0 students achieving high N-Gain and 21 students (70.0%) remaining in the low category. Cohen's d effect size was computed as d=1.213, classified as 'large' (d>0.8), indicating that the experimental posttest mean lies 1.213 standard deviations above the control mean.

Table 9. N-Gain and Effect Size Summary

Group	Mean Pretest	Mean Posttest	Mean N-Gain	N-Gain Category	Cohen's d	Effect Category
Experimental (PBL-Ethno)	59.53	81.03	0.557	Moderate	1.213	Large
Control (Conventional)	59.00	69.97	0.272	Low	-	-

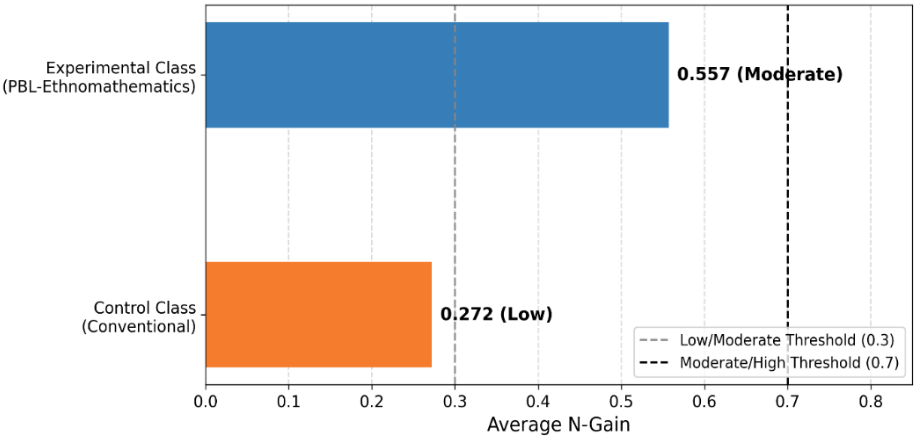

Figure 4. Comparison of Average N-Gain between the Experimental and Control Classes

These findings validate the theoretical integration of Ausubel's meaningful learning framework with Problem-Based Learning (PBL) and ethnomathematical principles as a coherent and evidence-based approach to spatial geometry instruction. From the perspective of meaningful learning, students develop stronger conceptual understanding when new mathematical ideas are connected to prior knowledge, familiar experiences, and meaningful contexts. In this study, the integration of local Bima cultural contexts, including Uma Lengge vernacular architecture and Bima geometric carvings, effectively activated students' prior geometric knowledge and strengthened conceptual connections between cultural representations and mathematical understanding of spatial shapes. This finding is consistent with Annajmi et al. (2026), who documented substantial gains through culturally contextualized PBL, and ethnomathematical integration can shift mathematics instruction toward culturally relevant and sustaining practices while maintaining mathematical depth.

The strong learning improvement observed in the experimental class can also be explained by the characteristics of PBL as an active and inquiry-oriented instructional model. PBL enables students to investigate authentic problems, collaborate with peers, construct mathematical representations, and communicate their reasoning. Almulla (2020) emphasized that project- and problem-oriented learning increases student engagement because learners are positioned as active participants in the learning process. Similarly, Guo et al. (2020) reported that student-centered learning designs, when supported by authentic tasks and collaboration, contribute positively to learning outcomes. These arguments are further reinforced by Zhang and Ma (2023), whose meta-analysis showed that project-based learning has a significant positive effect on students' learning achievement. Therefore, the large effect size in this study (Cohen's d = 1.213) suggests that the improvement was not merely caused by the use of cultural objects, but by the systematic integration of cultural context, problem solving, group investigation, and guided reflection.

The findings are also aligned with broader evidence on active learning. Theobald et al. (2020) found that active learning can reduce achievement gaps by providing more inclusive opportunities for students to participate and construct understanding. In the present study, the PBL-Ethnomathematics framework created such opportunities by allowing students to observe Uma Lengge, identify geometric structures, discuss spatial properties, and translate cultural artifacts into formal mathematical representations. This process supported students in moving from concrete cultural experience to abstract geometric reasoning.

The improvement in students' spatial shape representation understanding is strongly supported by research on the relationship between spatial reasoning and mathematical ability. Xie et al. (2020) demonstrated through meta-analysis that spatial ability is significantly associated with mathematical performance. Hawes and Ansari (2020) further explained that the relationship between spatial and mathematical skills is supported by cognitive mechanisms that help learners visualize, transform, and structure mathematical information. Lowrie et al. (2020) also emphasized the importance of identifying mechanisms that enable the transfer from spatial reasoning to mathematical understanding, while Lowrie et al. (2021) showed that spatial intervention programs can improve both spatial reasoning and mathematics performance. These studies support the interpretation that students' exposure to culturally grounded spatial objects, such as Uma Lengge and Bima carvings, helped them develop stronger representational fluency in geometry.

The ethnomathematical dimension of this study is also consistent with Indonesian and international mathematics education literature. Turmuzi et al. (2023) conducted a comprehensive content analysis of Indonesian ethnomathematics publications and confirmed a growing trend toward studies that situate geometric learning within cultural practice. Sudirman et al. (2020) demonstrated the viability of integrating ethnomathematics into augmented reality technology for geometry learning, establishing a technological precedent that complements the culturally grounded approach used in this study. In addition, Prahmana and D'Ambrosio (2020) showed that cultural patterns, such as batik motifs, can serve as meaningful resources for learning geometry while also transmitting cultural values. These studies indicate that ethnomathematics can make geometry more contextual, meaningful, and culturally responsive without reducing mathematical rigor.

Although this study emphasized physical cultural artifacts and classroom-based PBL activities, the findings also open possibilities for future integration with digital learning environments. Hillmayr et al. (2020) found that digital tools can enhance mathematics and science learning when they are aligned with instructional goals. Jong et al. (2020) showed that immersive video-based virtual reality can enrich learning experiences by helping students engage with spatial and contextual information. Pellas et al. (2020) similarly reported that immersive virtual reality has strong potential in STEM education, particularly for visualizing complex concepts. In addition, Koh and Kan (2021) highlighted the need to consider students' readiness and desired e-learning experiences, while Zhao et al. (2021) emphasized the importance of digital competence in supporting technology-based learning. Scherer et al. (2020) further noted that teachers' technology acceptance is an important factor in successful digital learning implementation. These studies suggest that future development of PBL-Ethnomathematics may incorporate digital or augmented representations of Uma Lengge and other Bima cultural artifacts to strengthen spatial visualization and conceptual understanding.

Overall, these findings indicate that PBL assisted by ethnomathematics provides a powerful instructional framework for spatial geometry learning. By connecting prior cultural knowledge with formal mathematical concepts, the model supports meaningful learning, active engagement, spatial reasoning, and culturally responsive mathematics instruction. The empirical results of this study therefore extend previous findings by demonstrating that local Bima cultural artifacts can be systematically integrated into PBL to improve students' understanding of spatial shape representation in junior high school mathematics.

CONCLUSION

This study has established robust empirical evidence for the effectiveness of the Problem-Based Learning model assisted by Ethnomathematics in improving spatial shape representation understanding among junior high school students in Kabupaten Bima. Two principal conclusions are drawn. First, there is a statistically significant difference between the spatial shape representation understanding of students who received PBL-Ethnomathematics instruction and those who received conventional instruction ($t=4.699$, $df=58$, $p<0.001$), with the experimental class achieving a substantially higher posttest mean of 81.03 compared to 69.97 in the control class a practically meaningful difference confirmed by a large effect size of Cohen's $d=1.213$. Second, the PBL-Ethnomathematics model demonstrated moderate-to-strong effectiveness, as evidenced by a mean N-Gain of 0.557 (moderate category) in the experimental class versus 0.272 (low category) in the control class, with 76.7% of experimental students achieving moderate or high N-Gain compared to only 30.0% in the control group. Future research should extend this framework to multiple schools, examine long-term retention effects, and develop differentiated scaffolding protocols for low-achieving students.

RECOMMENDATION

Based on these findings, it is recommended that mathematics educators at the junior high school level in Eastern Indonesia, particularly in Bima Regency, consider adopting the PBL-Ethnomathematics framework as a culturally grounded instructional model for spatial geometry topics. Future research should extend this framework to multiple school sites, investigate long-term retention effects, and develop differentiated scaffolding protocols to optimize outcomes for students with varying prior knowledge levels within the PBL-Ethnomathematics context.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Mariamah	✓	✓											✓	
Nanang Diana	✓	✓											✓	✓
Syarifudin	✓	✓								✓			✓	✓
Muslim	✓	✓						✓		✓			✓	✓

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, S, upon reasonable request. The data, which contain information that could compromise the privacy of the junior high school student participants, are not publicly available due to ethical restrictions. The authors plan to deposit a de-identified version of the dataset in a public repository following completion of the publication process.

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