Ethnomathematics-Based Project-Based Learning with GeoGebra Application Support to Optimize Students' Mathematical Creativity

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***Abstract*—This study addresses the continued reliance on conventional mathematics instruction in elementary schools, which has proven inadequate in fostering students' creativity. It emphasizes the need for innovative pedagogies that incorporate local cultural elements and digital tools to create meaningful learning experiences. The study aims to: (1) assess the effects of ethnomathematics-based Project-Based Learning (PjBL) supported by GeoGebra on students' mathematical creativity; (2) examine the interaction between ethnomathematics-based PjBL and Problem-Based Learning (PBL) in enhancing creativity; (3) compare creativity outcomes among students with high ethnomathematics understanding across both models; and (4) analyze differences among students with low ethnomathematics understanding. Using a quasi-experimental 2 × 2 treatment by level design, the study was conducted in an elementary school in Bima Regency, Indonesia, involving 80 students from a population of 101. The findings indicate that both PjBL and PBL supported by GeoGebra significantly improved mathematical creativity. Furthermore, an interaction between the instructional models and ethnomathematics understanding was found to influence creativity positively. Notably, students with high and low levels of Ethnomathematics understanding exhibited greater creativity when taught through ethnomathematics-based PjBL compared to PBL. The study advocates for integrating local cultural contexts and digital technologies into instructional models to enhance mathematical creativity among elementary school students.**

***Keywords*—Project-Based Learning (PjBL), Problem-Based Learning (PBL), creativity, ethnomathematics, GeoGebra application**

I. INTRODUCTION

Education in Indonesia continues to face significant challenges, particularly in literacy, mathematics, and science. Based on the 2022 data from the Programme for International Student Assessment (PISA), merely 18% of students in Indonesia demonstrated mathematical skills at or above Proficiency Level 2. This percentage is significantly lower when compared to the Organisation for Economic Co-operation and Development (OECD) average, where approximately 69% of students attained the same level of proficiency. At Proficiency Level 2, students are expected to interpret simple situations and represent them mathematically, such as comparing the total distance between two alternative routes [1, 2]. Countries such as Singapore, Macau, and Japan recorded more than 85% of students reaching or exceeding this level, highlighting a significant gap between Indonesia and high-performing nation [3]. Although Indonesia's ranking in PISA has slightly improved compared to previous years, the average student scores in reading (359), mathematics (366), and science (383) remain far below the international average. Moreover, these scores are the lowest recorded during the 2022 PISA assessment period, equivalent to the achievements observed in 2003 and 2006. This suggests that initiatives aimed at enhancing educational quality in Indonesia have not yet produced substantial results.

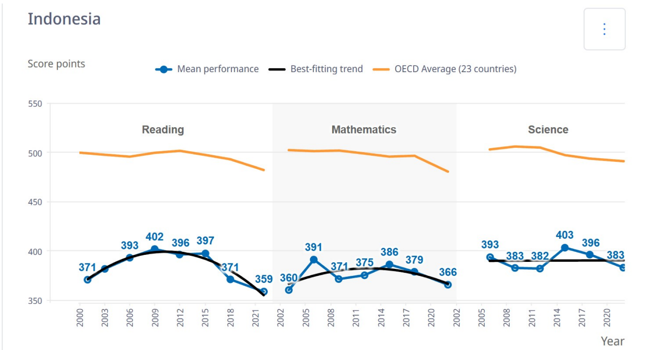

Fig. 1. Programme for International Student Assessment (PISA) in Indonesia [4, 5].

During the period of 2018 to 2022, a reduction in the performance gap between students with the highest and lowest scores in mathematics was observed. However, similar progress was not evident in the domains of reading and science. In addition, there was a troubling increase in the number of students who scored below the minimum proficiency threshold, with mathematics showing a rise of 5 percentage points and reading climbing by 19 percentage points. In science, however, no significant changes were recorded. On the other hand, almost no Indonesian students reached proficiency level 5 or 6 in mathematics. At these levels, students are expected to model complex situations and select appropriate problem-solving strategies. These skills are crucial in the context of 21st-century education, where problem-solving, critical thinking, and mathematical literacy are key competencies in addressing global challenges. Based on these findings, it is evident that improving the quality of education, particularly in mathematics and science learning, is an urgent necessity. The existence of this performance gap highlights the urgency of exploring innovative and effective instructional models, especially those that strengthen problem-solving abilities and promote the practical use of mathematical and scientific concepts in everyday situations.

Findings from the 2022 PISA indicate that Indonesia ranked 70th in mathematics among 81 participating countries, including 37 OECD member nations and 44

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partner countries, as depicted in Fig. 1. This data suggests that Indonesian students' mathematical proficiency remains at a significantly low level compared to other nation [6, 7]. One of the key factors that must be considered to enhance students' mathematical abilities is the importance of developing creativity in articulating, explaining, organizing, and consolidating mathematical thinking [8, 9].

Creativity in mathematics is a crucial aspect as it involves students' ability to generate original ideas, as well as meaningful and impactful work and actions [10, 11]. First, students must be able to articulate mathematical ideas, meaning they should be capable of transforming their understanding into clear and coherent statements. This mastery allows students not only to grasp concepts individually but also to communicate these ideas in a way that others can comprehend. Second, the ability to explain mathematical ideas is essential not only for students themselves but also for their peers. This capability enables students to deepen their understanding of mathematical concepts through verbalization and group discussions, which have been proven to enhance cognitive and collaborative skills. Third, students' ability to organize mathematical ideas into a logical structure is critical in mathematics learning. Coordinating their thoughts in this way helps them present information systematically, making it more accessible and understandable to their peers. This skill also supports students in tackling complex problems with a structured approach.

By fostering creativity, students gain the ability not only to comprehend and adapt mathematical concepts, but also to produce solutions that are original, innovative, and contextually appropriate [12, 13]. Creativity in mathematics encompasses important elements such as formulating original ideas and generating solutions that are not only conceptually meaningful but also applicable in real-world contexts. In mathematics education, creative students play an active role as problem solvers, who not only absorb knowledge passively but also initiate and apply new ideas to solve mathematical problems they encounter.

Ethnomathematics significantly contributes to nurturing and enhancing students' creative thinking abilities. By connecting mathematical concepts with local wisdom, ethnomathematics encourages students to explore and utilize cultural elements as resources in problem-solving [14, 15]. Ethnomathematics enriches students' understanding, not only in terms of formal mathematical concepts but also in how these concepts are applied within cultural contexts and everyday life. Through the introduction of contextualized mathematical concepts, ethnomathematics provides a strong framework for creative thinking, enabling the solutions students generate to be more relevant to their environment. Furthermore, ethnomathematics enhances student engagement, both emotionally and cognitively, which ultimately improves their ability to generate more original and innovative solutions [16, 17]. By linking mathematics to familiar cultural experiences, students feel more connected to the material, boosting their confidence in solving problems.

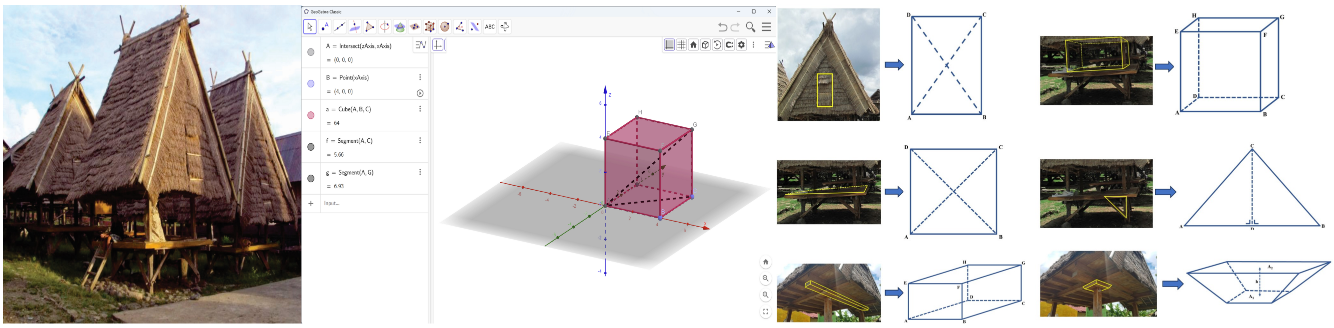

Fig. 2. Design of the ethnomathematics-based Project-Based Learning (PjBL) model with GeoGebra application support.

Fig. 2 above shows the design of an innovative ethnomathematics-based Project-Based Learning (PjBL) model by integrating mathematical concepts through the exploration of traditional traditional traditional houses of the Bima community using the GeoGebra application. Bima's traditional house, with a roof shape resembling a triangular prism and a trapezoidal and rectangular frame structure, is an interesting geometric study object. Through this approach, students are invited to reconstruct the shape of the traditional house in a digital model using GeoGebra, so that the concept of building spaces such as prisms, pyramids, and flat shapes can be visualized more realistically. This process not only trains students' understanding in calculating area, volume, and other geometric elements, but also hones their critical, creative, and innovative thinking skills. By connecting math concepts to local cultural objects, students can understand that math is not just an abstract theory, but an inseparable part of everyday life. This approach also encourages students to better appreciate their cultural heritage while mastering digital technology through the utilization of GeoGebra as an interactive learning medium. This learning model not only enriches the understanding of mathematical concepts contextually, but also builds innovative and culturally minded student characters, making it an effective strategy to enhance mathematical creativity in the modern era.

An effective approach to exploring students' mathematical creativity is through the implementation of PjBL and Problem-Based Learning (PBL) models. These instructional strategies prioritize the cultivation of critical thinking, creativity, and collaboration—key competencies for developing Pancasila student profiles. The PjBL model, in particular, encourages learners to independently explore, design, and carry out projects that are closely connected to real-life situations [18–20]. On the other hand, the PBL approach engages students in actively identifying and solving real-life problems, providing opportunities for them to enhance their creativity through the process of critical problem-solving [21–23].

In the context of ethnomathematics, which emphasizes the integration of local culture in mathematics learning, both

PjBL and PBL provide students with opportunities to explore mathematical concepts that are relevant to their lives and cultures. For instance, through PjBL, students may be tasked with creating projects related to local customs, allowing them to see the connection between mathematical concepts and their cultural practices. In contrast, PBL presents students with real-world problems related to mathematics within a cultural context, challenging them to think creatively in finding solutions.

The use of GeoGebra in mathematics education is based on the principle that this software can facilitate the visualization of concepts, manipulation of mathematical objects, and interactive exploration, which enhances students' understanding of abstract material. According to Owusu *et al*. [24], GeoGebra offers dynamic features that allow students to build and modify geometric or algebraic representations more flexibly. In the context of ethnomathematics-based PjBL, GeoGebra can be used to connect mathematical concepts with cultural elements by modeling traditional forms or geometric shapes found in daily life. Research by Nasrullah *et al*. [25] demonstrates that integrating GeoGebra into PjBL enhances student engagement, facilitates conceptual understanding, and encourages greater creativity in solving mathematical problems.

Support from the GeoGebra application in PjBL is evident in its ability to provide various exploration and simulation tools that can be integrated into the stages of PjBL. These stages include project planning, cultural data collection (ethnomathematics), analysis, and the creation of a final product that demands students' mathematical creativity. Research by Ishartono *et al*. [26] emphasizes that the use of GeoGebra enriches the learning experience as students can independently manipulate mathematical objects, experiment with various problem-solving strategies, and observe the direct impact of any changes they make to parameters. Therefore, the utilization of GeoGebra not only enhances conceptual understanding and higher-order thinking skills but also fosters the generation of new, more creative ideas as students integrate mathematical concepts with cultural contexts in ethnomathematics learning.

Implementing both learning models not only strengthens students' creative abilities in mathematics but also cultivates character traits like collaboration, self-reliance, and reflective thinking—qualities that are in harmony with the attributes of Pancasila learners [27, 28]. In practice, the teacher acts as a facilitator, guiding students to develop their creative ideas through PjBL and problem-solving, while ensuring that local cultural values are preserved through the ethnomathematics approach. This strategy serves as an effective solution to enhance students' mathematical creativity.

Several studies have investigated how these learning models affect students' mathematical creativity, especially within the framework of Pancasila student profile and the integration of ethnomathematics in education, aiming to identify which model yields a greater impact. Both models are recommended by the ministry of education and culture because they encourage students to learn independently, think critically, and solve problems in innovative ways. Researchers are interested in examining how each of these models can contribute to the development of students' creativity within the framework of ethnomathematics.

This research presents significant novelty compared to previous studies, particularly in the learning model that integrates ethnomathematics as a moderating variable in the development of students' mathematical creativity. The Pancasila student profile represents a concrete result of the implementation of Indonesia's most recent educational reform, the Merdeka Curriculum [29, 30], the Merdeka Curriculum aspires to shape a generation that excels not only in academics but also embodies strong character grounded in Pancasila values. Through its six core dimensions—faith in God and moral integrity, global-mindedness, collaboration, independence, critical thinking, and creativity—the curriculum directs students toward becoming adaptable individuals who are prepared to meet global demands while preserving their national identity.

Unlike previous studies that primarily focus on the development of mathematical skills in a formal and abstract context, this research emphasizes the importance of local wisdom as a foundation for strengthening students' mathematical creativity. Furthermore, the innovation of this study lies in how it connects cultural contexts with modern mathematics, offering an approach that is more relevant and meaningful for students. This study holds significant value as it addresses a gap in existing literature, where the incorporation of local cultural elements in fostering students' cognitive abilities—especially in the creativity aspect of the Pancasila student profile—is still limited. Consequently, this research contributes not only to the theoretical advancement of mathematics education but also offers practical recommendations for implementing more contextual and inclusive learning approaches.

To address the aforementioned issues, this research seeks to: (1) explore the impact of implementing an ethnomathematics-based PjBL model enhanced by the use of the GeoGebra application on students' mathematical creativity; (2) examine the interaction effects of ethnomathematics-integrated learning models on students' creative mathematical thinking; (3) assess variations in mathematical creativity among students with a strong grasp of ethnomathematics when taught using the GeoGebra-supported model; and (4) evaluate creativity differences in students with limited ethnomathematics comprehension who experience the same instructional approach.

II. Methodology

This study uses quantitative research with an experimental design by level 2 × 2 to measure the results of students' mathematical creativity. In this design, there are two independent variables, each divided into two levels, allowing for the examination of the interaction between these variables in influencing students' mathematical creativity [31]. The research design refers to Table 1, which shows the combination of treatments based on variations in the levels of both variables. The results will illustrate to what extent these factors contribute to the development of students' mathematical creativity, aligned with the dimensions in the Pancasila student profiles.

Table 1 illustrates the combination of ethnomathematics and GeoGebra within the PjBL and PBL learning models designed to help students understand mathematical concepts contextually. In this research, ethnomathematics plays an important role as an approach that links mathematical concepts with local wisdom, in this case the culture of the Bima people. Ethnomathematics aspects studied include geometric shapes in Bima traditional houses, traditional carving patterns, and calculation concepts applied in the construction of these traditional buildings. The instrument used to measure students' understanding of ethnomathematics includes a written test in the form of description questions that assess students' ability to identify, analyze, and relate mathematical concepts to local cultural elements. The assessment is carried out using an indicator-based assessment rubric such as accuracy in identifying ethnomathematics elements, the ability to relate mathematical concepts to local culture, and creativity in visualizing these concepts through the GeoGebra application. GeoGebra is used as a tool that allows students to reconstruct geometric shapes from Bima cultural elements visually and interactively, such as building models of triangular prisms, pyramids, and other spatial shapes found in traditional houses. With this approach, students not only understand mathematical concepts contextually, but also develop critical thinking skills, problem solving, and the use of technology in mathematics learning [32, 33]. The combination of ethnomathematics and GeoGebra in the PjBL and PBL models is designed to help students understand the mathematics concepts contextually.

Table 1. Experimental research design by level 2 × 2

Attribute Variables Ethnomathematics (B)	Treatment Variables (A)	
	PjBL (A1)	PBL (A2)
High Ethnomathematics with GeoGebra Support (B_1)	A_1B_1 (20 students)	A_2B_1 (20 students)
Low Ethnomathematics with GeoGebra Support (B_2)	A_1B_2 (20 students)	A_2B_2 (20 students)

[A1B1] Treatment using PjBL for students with High Ethnomathematics and GeoGebra Support; [A1B2] Treatment using PjBL for students with Low Ethnomathematics and GeoGebra Support; [A2B1] Treatment using PBL for students with High Ethnomathematics and GeoGebra Support; [A2B2] Treatment using PBL for students with Low Ethnomathematics and GeoGebra Support.

This research took place at a public elementary school located in Bima Regency, West Nusa Tenggara Province, Indonesia, and employed an experimental method using a 2 × 2 factorial design by level. From a total population of 101 students, a sample of 80 participants was chosen, determined by a 95% confidence interval and a 5% margin of error. The sample was taken from Sekolah Dasar Negeri (SDN) Rada, Bolo District, Bima Regency, which served as the experimental class, and SDN Nggembe, Bolo District, Bima Regency, which served as the control class. The subjects in this study had an average age of approximately 9 years. The research procedure follows the design outlined in Table 2, utilizing a 2 × 2 experimental by level design. Within this research design, the experimental group received instruction through the PjBL model, whereas the control group was taught using the PBL approach. Each group comprised students with both high and low levels of ethnomathematics understanding, and all participants were supported with the use of GeoGebra software throughout the learning activities.

After administering the ethnomathematics test, the results showed that 40 students had high ethnomathematics levels, while another 40 students had low ethnomathematics levels. Consequently, both the experimental and control classes comprised 40 students each, evenly distributed between students with high and low ethnomathematics levels. The sampling technique involved randomly selecting public elementary schools within Bima Regency. On average, these schools had two classes each. Based on this selection, SDN Rada was designated as the experimental class, while SDN Nggembe was designated as the control class.

In this study, the data collection technique was carried out through a 30-question essay test designed to measure students' understanding of the concept of ethnomathematics. This test covers aspects such as the ability to identify geometric shapes in local culture, analyze mathematical patterns in the tradition of the Bima community, and apply these concepts in GeoGebra-based problem solving. The questions were also structured to reflect the six core dimensions of the Pancasila student profile, which encompass faith in God and noble character, global diversity, collaboration, independence, critical thinking, and creativity. This approach not only helps students grasp mathematical concepts within real-life contexts, but also nurtures the development of positive character traits aligned with Pancasila values, particularly in fostering creativity. This dimension is reflected in the students' ability to generate innovative ideas in connecting mathematical concepts with local cultural elements. By utilizing the GeoGebra application, students are encouraged to design visual models that represent the geometric shapes of Bima's cultural heritage, such as traditional houses or decorative patterns. This process trains students to think creatively in finding unique solutions, developing math-based visual design skills, and expressing their ideas in original and meaningful ways. This approach is expected to foster students' creativity based on a deep understanding of culture and mathematical knowledge.

Based on the characteristics of creativity outlined in the operational definition, the indicators for the mathematical creativity variable have been determined. The instrument grid for mathematical creativity can be seen in Table 2, which is presented as follows:

Table 2. Instrument grid for students' mathematical creativity [34]

No	Dimension	Indicator	Item Number	Number of Questions
1	Original Ideas	Generating unique and original ideas	1	10
2	Original Works	Producing original and creative works	2	10
3	Original Actions	Generating new and different actions or solutions	3	10
		Total Questions		30

To determine students' mathematical creativity abilities, the following rubric or assessment guidelines are used:

Table 3. Assessment rubric for students' mathematical creativity [34]

No	Indicator	Measured Aspects	Scorer
1	Original Ideas	Uniqueness and creativity of ideas	Very Unsatisfactory Unsatisfactory
2	Original Works	Quality and authenticity of the produced work	Fairly Satisfactory Satisfactory
3	Original Actions	Innovation and courage in taking new actions	Very Satisfactory

Table 3 was used as the basis for assessing students' mathematical creativity, which was then analyzed using SPSS version 27 to ensure accuracy and precision in hypothesis testing. The first stage of data analysis involved conducting a descriptive analysis to obtain an overview of the research data, including the mean, standard deviation, as well as the minimum and maximum values for each treatment group. This descriptive analysis aimed to understand the data distribution and provide fundamental information about the variables studied. To verify that the dataset met the assumptions necessary for conducting a two-way Analysis of Variance (ANOVA), tests for normality and homogeneity were applied. The normality of the data was assessed using either the Kolmogorov-Smirnov or Shapiro-Wilk method, while Levene's Test was employed to evaluate the homogeneity of variances. These preliminary tests are essential to confirm that the data follows a normal distribution and that the variance across groups is consistent.

After the assumptions were met, two-way ANOVA was used to test the differences in the effects between PjBL and PBL on students' mathematical creativity, as well as to explore the impact of ethnomathematics levels (high and low) on students' mathematical creativity. Additionally, ANOVA was used to evaluate the interaction between the learning models and the ethnomathematics level in influencing students' mathematical creativity. If the ANOVA results show a significant F value with a significance level of p <0.05, it indicates a significant difference between the groups under study. For further analysis, a t-test was conducted as a post-hoc test to determine which group had significantly higher ethnomathematics. The t-test was used to compare the means of the two treatment groups in more detail.

First Hypothesis:
H_0: $\mu_{A1} < \mu_{A2}$;
H_1: $\mu_{A1} > \mu_{A2}$.
Second Hypothesis:
H_0: $Int_{A \times B} = 0$;
H_1: $Int_{A \times B} \neq 0$.
Third Hypothesis:
H_0: $\mu_{A1B1} < \mu_{A2B1}$;
H_1: $\mu_{A2B1} > \mu_{A2B1}$.
Fourth Hypothesis:
H_0: $\mu_{A1B2} < \mu_{A2B2}$;
H_1: $\mu_{A1B2} < \mu_{A1B2}$.

III. Results

A. Data Description

Table 4 presents the results of the data description after the implementation of the PjBL and PBL models on the impact of students' mathematical creativity based on their ethnomathematics with the support of the GeoGebra application. The descriptive results are presented as follows:

Table 4. Results of students' mathematical creativity description

Class	Creativity	N	Max	Min	Average	SD
PjBL	High	20	93	80	87.45	3.60
	Low	20	62	53	57.35	2.77
	All Students	40	93	53	72.4	15.56
PBL	High	20	91	78	85.55	3.61
	Low	20	60	51	55.35	2.77
	All Students	40	91	51	70.4	15.6

B. Analysis Requirement Test

1) Results of normality and homogeneity tests on students treated with PjBL and PBL based on ethnomathematics with GeoGebra application support

Table 5 presents the results of the normality test on the mathematical creativity scores of students who received instruction through the PjBL and PBL models. The analysis of the normality test for students who received instruction through both the PjBL and PBL models revealed that the mathematical creativity scores met the criteria for normal distribution. For the PjBL group, the Kolmogorov-Smirnov test yielded a significance value of 0.200 (>0.05), while the Shapiro-Wilk test showed 0.530 (>0.05). Similarly, in the PBL group, the Kolmogorov-Smirnov value was 0.200 (>0.05), and the Shapiro-Wilk test produced a significance of 0.236 (>0.05). These findings confirm that the mathematical creativity data from the 40 students in each group are normally distributed.

Table 5. Results of the normality test

Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PjBL	0.148	20	0.200*	0.959	20	0.530
PBL	0.153	20	0.200*	0.940	20	0.236

* This is a lower bound of the true significance; [a] Lilliefors significance correction. Same below.

Table 6. Results of the homogeneity test from students' mathematical creativity values

Levene Statistic	df1	df2	Sig.
0.521	1	38	0.475

Table 6 presents the results of the homogeneity test on the mathematical creativity scores of students who received instruction using the PjBL and PBL models. Based on the analysis results, a significance value of 0.475 > 0.05 was obtained, which indicates that the data on students' mathematical creativity scores have homogeneous variance.

2) Normality and homogeneity test of PjBL and PBL on students with high ethnomathematics supported by GeoGebra application

Table 7 presents the results of the normality test analysis on students who were given treatment using the PjBL and PBL models with high levels of ethnomathematics. Based on these results, the significance values of students' mathematical creativity are as follows:

1) In the group of students with high levels of ethnomathematics taught using the PjBL model, the Kolmogorov-Smirnov test returned a value of 0.200 (>0.05), while the Shapiro-Wilk test showed a significance of 0.466 (>0.05).
2) Likewise, for students with high ethnomathematics understanding taught using the PBL model, the Kolmogorov-Smirnov test yielded a result of 0.200 (>0.05), and the Shapiro-Wilk test produced a significance value of 0.325 (>0.05).

Table 7. Results of the normality test

Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PjBL and High Ethnomathematics	0.200	10	0.200*	0.932	10	0.466
PBL and High Ethnomathematics	0.206	10	0.200*	0.916	10	0.325

This indicates that the data on students' mathematical creativity from 40 samples who were treated with PjBL and PBL are normally distributed.

Table 8. Homogeneity test results PjBL and PBL with ethnomathematics high

Levene Statistic	df1	df2	Sig.
0.300	1	18	0.591

Table 8 presents the results of the homogeneity test on students with high levels of ethnomathematics who were taught using either the PjBL or PBL models. Based on the test results, a significance value of 0.591 (>0.05) was obtained. This indicates that the variance in students' mathematical creativity scores across the two groups is homogeneous, in accordance with the assumptions required for the homogeneity test.

3) Normality and homogeneity test of PjBL and PBL for students with low ethnomathematics supported by GeoGebra application

Table 9 presents the results of the normality test analysis for students who received instruction using the PjBL and PBL models with low levels of ethnomathematics. The results show the following significance values for students' mathematical creativity: The Kolmogorov-Smirnov value is 0.200 > 0.05, and the Shapiro-Wilk test shows a significance value of 0.691 > 0.05 for students taught using the PjBL model. Furthermore, for students taught using the PBL model with low ethnomathematics, the Kolmogorov-Smirnov value is 0.200 > 0.05, and the Shapiro-Wilk value is 0.190 > 0.05. This indicates that the data on students' mathematical creativity from the 40 sample students who received PjBL and PBL treatments with low ethnomathematics are normally distributed.

Table 9. Normality test results

Class	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PjBL and Low Ethnomathematics	0.174	10	0.200*	0.952	10	0.691
PBL and Low Ethnomathematics	0.202	10	0.200*	0.894	10	0.190

Table 10. Homogeneity test results PjBL and PBL with ethnomathematics low

Levene Statistic	df1	df2	Sig.
1.232	1	18	0.282

Table 10 presents the results of the homogeneity test for students with low levels of ethnomathematics who were taught using the PjBL and PBL models. The test results show a significance value of 0.282, which exceeds 0.05. This indicates that the mathematical creativity scores in both groups have equal variance, thus fulfilling the assumption of variance homogeneity.

C. Hypothesis

1) The results of students' mathematical creativity who were given PjBL and PBL with the support of the GeoGebra application on students' mathematical creativity

The results of hypothesis testing using two-way ANOVA showed that students taught with either the PjBL or PBL learning models yielded an F-value of 12.84. At a 0.05 significance level, with degrees of freedom $df_1 = 2$ and $df_2 = 18$, the critical F-table value was 3.55. Since the obtained F-value is greater than the table value, the null hypothesis (H_0) is rejected. This indicates that the type of instructional model used—PjBL or PBL—significantly influences students' mathematical creativity, as shown in Table 11.

The analysis results show that the calculated F-value of 12.84 exceeds the critical F-table value of 3.55, resulting in the rejection of the null hypothesis (H_0). This finding signifies that there is a statistically significant difference in mathematical creativity scores between students subjected to different instructional approaches. Moreover, the acceptance of the alternative hypothesis (H_1) confirms that students who experienced the PjBL model achieved higher levels of mathematical creativity compared to those who participated in the PBL model.

Table 11. Results of the mathematical creativity test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1521.875[a]	3	507.292	8.504	0.000
Intercept	151,905.625	1	151,905.625	2546.497	0.000
Learning in Class	765.625	1	765.625	12.835	0.001
Ethnomathematics	75.625	1	75.625	1.268	0.268
Learning in Class * Ethnomathematics	680.625	1	680.625	11.410	0.002
Error	2147.500	36	59.653	-	-
Total	155,575.000	40	-	-	-
Corrected Total	3669.375	39	-	-	-

[a] R Squared = 0.415 (Adjusted R Squared = 0.366); * Interaction between Learning in Class and Ethnomathematics in SPSS aplication.

2) The interaction of PjBL and PBL with ethnomathematics on students' mathematical creativity

The analysis results reveal an interaction effect between the learning approaches—PjBL and PBL—and ethnomathematics on students' mathematical creativity. This is evidenced by a significance value of 0.002, which is below the 0.05 threshold, indicating a statistically significant interaction. Therefore, it can be concluded that the combination of learning method and ethnomathematics understanding plays a meaningful role in influencing students' mathematical creativity.

3) The difference in mathematical creativity between students who were given PjBL and PBL and students who have high ethnomathematics with the support of the GeoGebra application on students' mathematical creativity

The t-test analysis showed that students with a high level of ethnomathematics understanding who were taught using the PjBL model and those who received instruction through the PBL model produced a t-value of 5.04. At a 0.05 significance level with 18 degrees of freedom, the critical t-table value was 2.10. Since the obtained t-value exceeds this threshold, the null hypothesis (H_0) is rejected. This confirms a statistically significant difference in mathematical creativity between the two learning models, even though both groups shared the same level of ethnomathematics understanding. The acceptance of the alternative hypothesis (H_1) suggests that the PjBL model was more effective in enhancing students' mathematical creativity under these conditions, as shown in Table 12.

Table 12. Results of the independent samples test

Higher Class Level		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PjBL and PBL with High	Equal variances assumed	0.300	0.591	5.037	18	0.000	17.000	3.375	9.910	24.090
Ethnomathematics	Equal variances not assumed	-	-	5.037	17.207	0.000	17.000	3.375	9.886	24.114

4) The difference in mathematical creativity between students treated with PjBL and PBL and students with low ethnomathematics with the support of the GeoGebra application on students' mathematical creativity

The results of the t-test analysis for students with low ethnomathematics understanding who were taught using either the PjBL or PBL models revealed a t-value of 1.42. With a significance level of 0.05 and 18 degrees of freedom, the corresponding t-table value is 2.10. Since the calculated t-value (1.42) is less than the critical value, the null hypothesis (H_0) is accepted. This indicates that there is no statistically significant difference in mathematical creativity between the two groups. Additionally, the acceptance of H_0 suggests that students with low ethnomathematics understanding who experienced the PjBL model showed lower creativity compared to those taught using the PBL model, despite both groups having the same level of ethnomathematics, as shown in Table 13.

Table 13. Results of the independent samples test

Lower Class Level		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
PjBL and PBL with Low	Equal variances assumed	1.232	0.282	1.42	18	0.889	500	3.532	−6.92	7.920
Ethnomathematics	Equal variances not assumed	-	-	1.42	15.242	0.889	500	3.532	−7.02	8.017

IV. Discussion

The testing of the first, second, and third hypotheses resulted in the rejection of the null hypothesis (H_0) at a 0.05 significance level. In contrast, the fourth hypothesis test led to the acceptance of H_0 at the same significance level. These findings indicate that there is a meaningful interaction between the applied learning models and the integration of ethnomathematics in enhancing students' mathematical creativity. However, for the fourth hypothesis, no significant difference was found in the mathematical creativity of students with low levels of ethnomathematics exposure across the different instructional models. The following section presents a detailed discussion of the research findings based on each tested hypothesis.

A. The Results of Students' Mathematical Creativity Who Were Given PjBL and PBL with the Support of the GeoGebra Application on Students' Mathematical Creativity

Based on the data analysis, it was found that there is a significant difference between the mathematical creativity skills of students who received the PjBL treatment and those who received the PBL treatment. The results of the study indicate that students who were given the PjBL treatment had higher creativity skills compared to students who received the PBL treatment.

This is in line with the theory proposed by Zhang and Ma [35], which states that PjBL provides students with the opportunity to develop creativity through a learning approach that emphasizes exploration, idea development, and the application of concepts into real-world projects. This model allows students to become more independent, critical, and collaborative in completing tasks.

On the other hand, PBL, which also encourages students to solve authentic problems, although effective in training problem-solving skills, tends to have a structure that is more focused on solving specific problems rather than fostering broad creative exploration. According to Amin *et al*. [36] PBL focuses more on having students solve one complex problem, which may limit the space for broader creativity.

Based on these results, it can be concluded that PjBL significantly enhances students' mathematical creativity skills compared to PBL.

B. The Interaction of PjBL and PBL with Ethnomathematics on Students' Mathematical Creativity

The data analysis results indicate a significant interaction between the learning model used and the application of ethnomathematics in affecting students' mathematical creativity skills. This shows a positive relationship between the implementation of PjBL with the integration of ethnomathematics in teaching, leading to an improvement in students' mathematical creativity skills.

Ethnomathematics, as a variable linking mathematical concepts with cultural and environmental contexts, plays an important role in enhancing students' mathematical creativity [37–39]. This study proves that the application of PjBL combined with elements of ethnomathematics can provide space for students to think creatively, use local wisdom to solve mathematical problems, and relate mathematical concepts to their daily lives. This aligns with the Pancasila student profile, which encourages students to have critical and creative thinking when facing problems [30, 40, 41].

Thus, it can be concluded that there is a significant interaction between the PjBL model and the application of ethnomathematics in improving students' mathematical creativity skills.

creativity skills.

C. The difference in Mathematical Creativity Between Students Who were Given PjBL and PBL and Students who have High Ethnomathematics with the Support of the GeoGebra Application on Students' Mathematical Creativity

In the third hypothesis testing, H0 was rejected, indicating a significant difference between students who received the PjBL treatment and students who received the PBL treatment among those with high ethnomathematics application. The analysis results show that students with high ethnomathematics application who were given PjBL have higher mathematical creativity skills compared to students with high ethnomathematics application who received PBL.

Students with high ethnomathematics application are able to link mathematical concepts with their cultural experiences, which can enhance creativity in problem-solving. PjBL provides an opportunity for students with high ethnomathematics application to explore creative ideas through projects relevant to their daily lives [42–44], in line with the Pancasila student profile principles that emphasize innovative and independent thinking.

In contrast, PBL directs students to focus on solving one specific problem, which may not always be relevant to their cultural context, limiting the opportunity to develop creativity based on ethnomathematics. Based on the results of descriptive statistical analysis and t-tests, it can be concluded that PjBL is more effective in enhancing the mathematical creativity of students with high ethnomathematics application.

D. The Difference in Mathematical Creativity between Students Treated with PjBL and PBL and Students with Low Ethnomathematics with the Support of the GeoGebra Application on Students' Mathematical Creativity

The results of the fourth hypothesis test indicate that the null hypothesis (H_0) is accepted, suggesting that there is no significant difference in mathematical creativity between students with low ethnomathematics exposure who were taught using either the PjBL or PBL learning models [28, 45, 46]. The statistical analysis indicates that students with low levels of ethnomathematics application exhibit no significant difference in their mathematical creativity skills, regardless of whether they were taught using the PjBL or PBL model.

Students with low ethnomathematics application tend to have difficulty linking mathematical concepts with their environment or cultural experiences, thus limiting their creative thinking process. PjBL may pose a challenge for students with low ethnomathematics application because they are less familiar with the cultural contexts relevant to completing projects [27, 47]. However, students with low ethnomathematics application who participated in PBL may feel more comfortable with the more structured approach focused on problem-solving.

Based on the results of the analysis and discussion, it can be concluded that for students with low ethnomathematics application, neither the PjBL nor the PBL learning model has a significant impact on their mathematical creativity abilities.

V. CONCLUSION

Based on the data analysis and research findings regarding the impact of PjBL and PBL on students' mathematical creativity in line with the Profile of Pancasila Students, as viewed through the lens of ethnomathematics, the following conclusions that based on the statistical test results, the average score for students' mathematical creativity who learned through PjBL is 85.75, while students who learned through PBL had an average score of 78.40. The t-test results show a significance value of 0.02 (<0.05), indicating a significant difference in the mathematical creativity of students who received the PjBL treatment compared to those who received the PBL treatment. This suggests that the PjBL method is more effective in enhancing students' mathematical creativity in line with the profile of Pancasila students.

Meanwhile, the interaction of PjBL and PBL with ethnomathematics on students' mathematical creativity based on the results of the two-way interaction test showed an F value of 4.89 with a significance value of 0.01 (<0.05), indicating a significant interaction between the learning methods (PjBL and PBL) and the level of ethnomathematics in influencing students' mathematical creativity. In other words, the impact of the learning methods on students' mathematical creativity varies based on the level of ethnomathematics the students possess.

Students with a high level of ethnomathematics who learned through PjBL had an average creativity score of 88.50, which is higher compared to students with a high level of ethnomathematics who learned through PBL, with an average score of 80.20. The t-test results showed a significance value of 0.03 (<0.05), indicating that the PjBL method is more effective in enhancing the mathematical creativity of students with a high level of ethnomathematics. Meanwhile from students with a low level of ethnomathematics who learned through PjBL had an average creativity score of 78.30, while students with a low level of ethnomathematics who learned through PBL had an average score of 77.90. The t-test results showed a significance value of 0.74 (>0.05), indicating that there is no significant difference between the two learning methods for students with a low level of ethnomathematics. This suggests that both PjBL and PBL have a relatively equal impact on students' mathematical creativity with low levels of ethnomathematics.

The findings of this research offer valuable insights for educators in selecting appropriate instructional models to enhance students' mathematical creativity. The application of PjBL is proven to be more effective, especially for students with high ethnomathematics levels. Therefore, teachers are advised to further integrate PjBL that emphasizes local cultural values so that students can connect mathematical concepts to everyday life in a more meaningful way. In addition, the use of the GeoGebra application in learning can be continuously developed to support the visualization of mathematical concepts interactively. For further research, it is recommended that further exploration be carried out regarding other factors that can influence students' mathematical creativity, such as learning style, motivation, or social environment. Research with a wider scope and involving different levels of education is also recommended so that the research results can be more tested and have stronger generalizations.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

S contributed to the research design and provided overall guidance throughout the study; AAA was responsible for data collection, analysis, and manuscript writing; I assisted with the literature review, instrument validation, and final editing of the manuscript; all authors had approved the final version.

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