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Enhancing Conceptual Understanding of Plane Geometry through Tugu Yogyakarta Ethnomathematics Pop-Up Fourth-Grade

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Abstract

The abstract nature of geometry often creates a disconnect between mathematical concepts and students' daily lives, resulting in limited conceptual understanding in elementary education. This study aims to evaluate the effectiveness of an ethnomathematics-based pop-up book, centered on the Tugu Yogyakarta monument, in enhancing fourth-grade students' understanding of plane geometry. Using a quantitative, quasi-experimental, nonequivalent control-group design, the research involved 30 students at SD Netral C Yogyakarta, divided into an experimental and a control group. Data were collected via expert-validated multiple-choice tests and analyzed using descriptive and inferential statistics, including the Independent Sample t-Test. Results indicated that the data were normally distributed and homogeneous (p = 0.441). The Independent Sample t-Test yielded a t-count of 3.028 with a significance of 0.004, leading to the rejection of the null hypothesis. These findings demonstrate that students who used the ethnomathematics pop-up book achieved significantly higher conceptual understanding than those who used conventional textbooks. The integration of 3D visual media and local cultural icons effectively bridges abstract geometric properties with concrete spatial visualization, making it a viable alternative for meaningful mathematics instruction in elementary schools.

Keywords: Ethnomathematics, Tugu Yogyakarta, *Pop-up book*, Plane geometry, Conceptual Understanding

Meningkatkan Pemahaman Konsep Bangun Datar Siswa Kelas IV melalui Buku Pop-Up Etnomatematika Tugu Yogyakarta

Abstrak

Sifat abstrak geometri kerap menimbulkan keterputusan antara konsep-konsep matematika dan kehidupan sehari-hari siswa, sehingga berdampak pada rendahnya pemahaman konsep pada pendidikan di sekolah dasar. Penelitian ini bertujuan mengevaluasi efektivitas media pop-up book berbasis ethnomatematika yang berpusat pada Monumen Tugu Yogyakarta dalam meningkatkna pemahaman siswa kelas IV terhadap geometri bidang. Dengan menggunakan pendekatan kuantitatif melalui desain kuasi-eksperimen nonequivalent control group. Penelitian melibatkan 30 siswa di SD Netral C Yogyakarta yang dibagi kedalam kelompok eksperimen dan kelompok kontrol. Data dikumpulkan melalui tes pilihan ganda yang telah divalidasi oleh ahli, kemudian dianalisis menggunakan statistik deskriptif dan inferensial, meliputi uji Independent Sample t-Test. Hasil penelitian menunjukkan bahwa data berdistribusi normal dan bersifat homogen (p = 0,441). Uji Independent Sample t-Test menghasilkan nilai t-hitung sebesar 3,028 dengan signifikansi 0,004, sehingga hipotesis nol ditolak. Temuan ini menunjukkan bahwa siswa yang menggunakan pop-up book etnomatematika memperoleh pemahaman konsep yang secara signifikan lebih tinggi dibandingkan siswa yang menggunakan buku ajar konvensional. Integrasi media visual 3D dan ikon budaya lokal secara efektif menjembatani sifat abstrak karakteristik geometri dengan visualisasi spasial yang lebih konkret, sehingga dapat menjadi alternatif yang layak untuk pembelajaran matematika yang bermakna di sekolah dasar.

Kata kunci: Etnomatematika, Tugu Yogyakarta, Buku pop-up, Geometri bangun datar, Pemahaman konseptual

INTRODUCTION

Mathematics is one of the fundamental subjects that plays an important role in developing students' logical, analytical, systematic, critical, and creative thinking abilities. Through mathematics learning, students are expected to understand concepts, connect different concepts, and apply them in various real-life situations (Devioni et al., 2025). However, mathematics is still often perceived as a difficult, abstract, and less meaningful subject for most students. This perception is closely related to the symbolic nature of mathematical content and the use of conventional, teacher-centered teaching methods, which limit students' active participation in the learning process. One of the mathematical topics that frequently causes difficulties is plane geometry (Mufidah & Ishartono, 2024). Plane geometry requires students to understand basic concepts such as points, lines, angles, two-dimensional shapes, properties of plane figures, and the relationship among geometric elements.

Conceptual understanding in geometry requires not only mathematical skills but also visualization skills, spatial imagination, and logical reasoning. In reality, many students can memorize formulas for area and perimeter without truly understanding the meaning and concepts underlying those formulas (Oktavia et al., 2025; Prasetya et al., 2024). This condition causes students to experience difficulties when faced with contextual problems or questions that require flexible application of concepts. The low level of conceptual understanding in plane geometry may be influenced by several factors, including the limited use of instructional media by teachers, the lack of connection between the material and real-life contexts, and the minimal use of engaging and meaningful learning approaches (Andira et al., 2022). The media used in geometry instruction are often limited to two-dimensional images in textbooks or on the board, which are ineffective at helping students develop strong mental representations of geometric concepts. As a result, students tend to be passive, become easily bored, and show low motivation to explore the material in greater depth (Bidiyah et al., 2024).

In the context of twenty-first-century education, mathematics learning needs to be designed to be relevant, contextual, and meaningful. One relevant approach is ethnomathematics. Ethnomathematics is a field of study that connects mathematical concepts with local cultures that develop within communities (Ambrosio, 1985). Through ethnomathematics, mathematics learning becomes more closely connected to students' daily lives, thereby enhancing the meaning, relevance, and attractiveness of the learning process (Andini & Cahyanngsih, 2023). The use of local cultural elements in mathematics instruction has great potential to help students better understand concepts in context. Culture contains various forms, patterns, and structures that indirectly represent mathematical concepts, particularly geometry. Traditional buildings, ornaments, monuments, and cultural symbols can serve as valuable learning resources rich in geometric concepts (Arvianto et al., 2025). By integrating local culture into the learning process, students not only learn mathematics but also develop an understanding, appreciation, and sense of responsibility to preserve their regional culture.

One of the cultural icons rich in geometric elements is the Tugu Yogyakarta. This monument not only holds significant historical and philosophical value for the people of Yogyakarta, but also visually consists of various plane figures such as squares, rectangles, triangles, trapezoids, and circles (Sadana & Ibnu Wibisono, 2024). The proportions and symmetry of the Tugu Yogyakarta make it an authentic context for learning plane geometry (Febriana et al., 2022; Gebremeskel et al., 2025). The use of the Tugu Yogyakarta as a learning context allows students to observe and analyze geometric concepts through objects that are familiar and meaningful to them (Sulistyani et al., 2025). However, to make optimal use of this cultural context in learning, it is necessary to provide media that can present concrete and interactive visualizations.

A type of media that could support this is the pop-up book. A pop-up book is instructional media in the form of a book with three-dimensional elements that move or unfold when the pages are opened. The visual, interactive, and attractive characteristics of pop-up books can capture students' attention and help them transform abstract concepts into a more concrete understanding (Sitaresmi & Al Zitawi, 2025). The use of pop-up books in learning plane geometry provides a different learning experience compared to conventional textbooks. Through pop-up books, students can observe representations of plane figures in three-dimensional forms, examine the relationships among geometric elements, and understand concepts both visually and kinesthetically. Direct interaction with pop-up media also encourages students to be more active, explorative, and engaged in the learning process, which in turn can enhance their conceptual understanding (Mohamed & Kandeel, 2023). The integration of pop-up books with an ethnomathematics approach based on the Tugu Yogyakarta represents a relevant and contextual learning innovation.

Ethnomathematics pop-up books not only present plane geometry material but also connect it with cultural values and local wisdom (Huang, 2017; Batiibwe, 2024).

Through this learning media, students can explore geometric concepts such as area, perimeter, angles, and the properties of plane figures by observing parts of Tugu Yogyakarta presented visually in an engaging way. Consequently, the learning process becomes more meaningful as students learn from real, familiar objects in their environment. In addition to strengthening conceptual understanding, the use of ethnomathematics pop-up book media also has the potential to enhance students' motivation and promote a more positive attitude toward mathematics (Pratama & Yelken, 2024). Engaging and contextual learning media can help reduce mathematics learning anxiety while fostering curiosity and interest in learning. Students no longer view mathematics as a collection of abstract formulas but as a discipline that exists and provides practical value in everyday life, aligned with the culture they belong to.

Based on the above explanation, the low level of conceptual understanding in plane geometry is a problem that requires serious attention in mathematics learning. There is a need for innovative learning approaches that connect mathematical concepts to cultural contexts and are supported by engaging, interactive learning media. The ethnomathematics pop-up book based on the Tugu Yogyakarta serves as an alternative solution to enhance students' conceptual understanding of plane geometry. Through the integration of local culture and three-dimensional visual media, geometry learning is expected to become more concrete, meaningful, and enjoyable, thereby improving the overall quality of mathematics instruction and optimizing students' learning outcomes.

Previous studies have shown that ethnomathematics-based learning can improve students' mathematical understanding. The use of Tangerang batik as an ethnomathematics context has been proven to be more effective than conventional learning in enhancing students' comprehension of mathematical concepts(Febrianingsih et al., 2024). In addition, the use of cultural objects has been shown to help students visualize and understand geometric concepts more effectively (Bantaika et al., 2025). However, most of these studies still rely on two dimensional cultural representations and have not widely integrated interactive three-dimensional learning media. Furthermore, research that specifically uses the Tugu Yogyakarta as an ethnomathematics context in teaching plane geometry to fourth grade students remains very limited.

Based on these conditions, the question arises whether plane geometry learning that integrates the cultural context of Tugu Yogyakarta through pop-up book media can enhance students' conceptual understanding more effectively than conventional learning using textbooks. Therefore, this study aims to examine the effectiveness of the ethnomathematics-based Tugu Yogyakarta pop-up book in improving fourth-grade students' conceptual understanding of plane geometry. This study hypothesizes that students who learn using the ethnomathematics Tugu Yogyakarta pop-up book will achieve a higher level of conceptual understanding in plane geometry compared to those who learn through conventional textbook-based instruction.

METHODS

Research Design

This study employs a quantitative, quasi-experimental design. The non-equivalent control group design was selected because subjects were not randomly assigned to groups; instead, intact classes were utilized (Abraham & Supriyati, 2022; Cresswell & Poth, 2018). This study involved two groups: an experimental group using the "Tugu Yogyakarta Ethnomathematics Pop-Up Book" and a control group using conventional textbooks for plane geometry materials. This approach aims to objectively measure the influence of media intervention on the dependent variables.

Setting and Participants

The research was conducted at SD Netral C, located on Jalan Dagen No. 219, Sosromenduran, Gedongtengen, Yogyakarta. This site was selected based on the availability of digital multimedia infrastructure, adequate internet access, and the educators' openness to instructional technology innovation. The research population included all students in Class IV A, totaling 30 respondents. Sampling was conducted using a purposive sampling technique, where participants were selected based on specific criteria aligned with the research objectives. The subjects were divided into two balanced groups: the experimental class (15 students) and the control class (15 students).

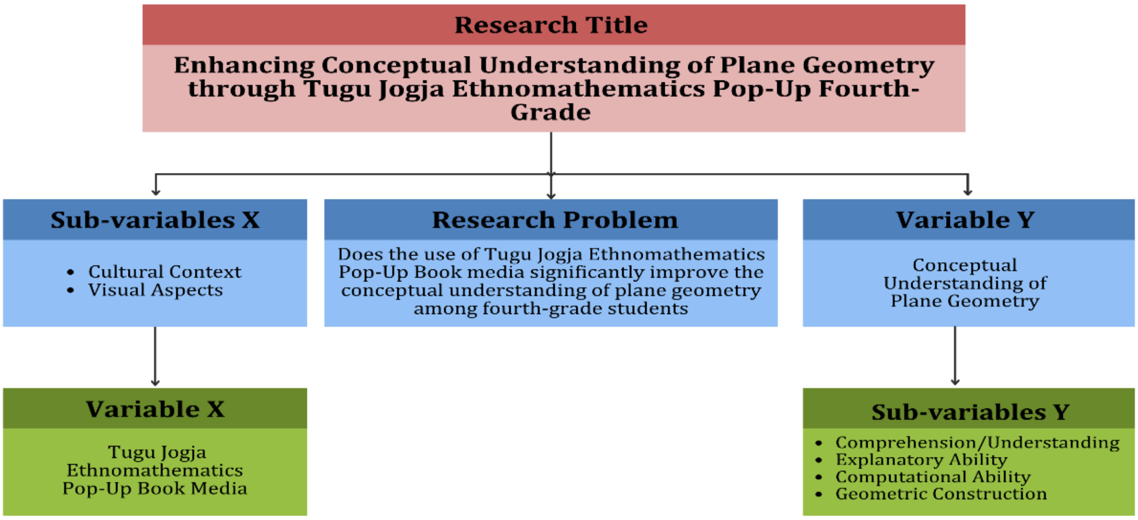

Figure 1. Conceptual Framework Diagram

Research Instruments

The primary research instrument was a multiple-choice test consisting of 20 items developed based on indicators of critical thinking and criteria of conceptual understanding in plane geometry (Cresswell & Poth, 2018; Facione, 2015). Each item was scored on a 0–100 scale and administered during both the pretest and posttest phases to measure students' conceptual understanding before and after the instructional intervention.

Prior to implementation, the instrument underwent expert validation to establish content validity, ensuring alignment with learning objectives, conceptual understanding indicators, and the cognitive characteristics of fourth-grade students. Following expert validation, the internal consistency of the instrument was empirically examined using Cronbach's Alpha. The reliability analysis was conducted using pretest data from 30 students (15 experimental and 15 control). The analysis yielded a Cronbach's Alpha coefficient of 0.82, exceeding the commonly accepted threshold of 0.70 and indicating good internal consistency, thus confirming the reliability of the instrument for educational research (Edelsbrunner et al., 2025).

Data Collection Procedures

Data were collected through tests, observations, and documentation. The test was administered in two stages, namely a pretest conducted before the instructional intervention and a posttest administered after the intervention. The experimental group received instruction using the Tugu Yogyakarta Ethnomathematics Pop-Up Book, while the control group was taught using conventional textbooks.

Classroom observations and documentation were used solely as supporting data to confirm the implementation of the learning process and student engagement in the experimental class. These data were recorded using observation guidelines and relevant documents, such as lesson plans and student worksheets, and were not subjected to statistical analysis but served to support the interpretation of the quantitative findings (Rusli et al., 2025).

Data Analysis Techniques

Data analysis was performed in two stages. First, descriptive statistical analysis was used to present data through mean, maximum, and minimum values. Second, inferential statistical analysis was conducted, including normality tests, homogeneity tests, and Independent Sample t-Tests at a 5% significance level, processed using SPSS version 23.

Following Royston's recommendation for sample sizes under 50, the Shapiro-Wilk test was applied for the normality test, where data are considered normally distributed if the significance value (Sig.) > 0.05. The homogeneity test utilized Levene's Statistics, with data considered homogeneous if Sig. > 0.05. Finally, the Independent Sample t-Test was performed to determine whether significant differences exist in student understanding between the experimental and control groups. The data was first tested to meet the assumptions of normality (Shapiro-Wilk test) and homogeneity of variance (Levene Test Statistics test).

Normality test results show that all pretest and posttest data in both groups have a Sig. Value between 0,254 and 0,688, which means the data is normally distributed. The results of the homogeneity test also showed a value of Sig. = 0,441, indicating that the variance of the two groups is homogeneous. Thus, the data meet the basic assumptions for the use of the Independent Sample T-Test. After fulfilling, the data were analyzed using the t-test (Independent Sample T-Test) to determine the significant difference between the experimental and control groups. In addition, N-Gain analysis was used to measure the effectiveness of the treatment based on the increase in student learning outcomes.

RESULTS AND DISCUSSION

Results

Descriptive Analysis of the Pretest

Descriptive analysis of the pretest was conducted to obtain an initial overview of students' understanding of plane geometry concepts in the experimental and control classes before the treatment was implemented. This stage is essential in quasi experimental research using a nonequivalent control group design to ensure that any differences in final outcomes are genuinely attributable to the treatment rather than to preexisting differences in students' initial abilities. The parameters examined included the mean score, standard deviation, minimum score, and maximum score for each group.

Table 1. Descriptive Analysis of Pretest Results

Class	Descriptive Analysis			
	Mean	Std. Deviation	Minimum	Maximum
Class Experiment	56.73	7.99	45	75
Class Control	60.13	8.79	48	75

Based on Table 1, the experimental class obtained a pretest mean score of 56.73 with a standard deviation of 7.99, whereas the control class achieved a mean score of 60.13 with a standard deviation of 8.79. This difference in means indicates that, descriptively, the control class had slightly higher initial ability than the experimental class. Nevertheless, the relatively comparable standard deviations in both groups suggest a similar level of variability in students' abilities. Therefore, further inferential analysis is required to determine whether the observed difference in mean scores is statistically significant.

Pretest Normality and Homogeneity Tests

Prior to comparing pretest mean scores, the data were examined to ensure that the assumptions for parametric analysis were satisfied, namely normality of distribution and homogeneity of variance. Data normality was tested using the Shapiro–Wilk test due to the sample size being fewer than 50 students in each group, while homogeneity of variance was assessed using Levene's test, a robust method for evaluating equality of variances between independent groups (Gastwirth et al., 2009).

Table 2. Normality Pretest

Pretest Results	Shapiro-Wilk		
	Statistic	df	Sig.
Class Experiment	0.960	15	0.688
Class Control	0.928	15	0.254

Table 3. Homogeneity of Variance Test for the Pretest

Pretest Results	Levene Statistic	df1	df2	Sig.
Based on Mean	0.222	1	28	0.441

The Shapiro–Wilk test results indicate that the pretest data in both the experimental ($p = 0.688$) and control ($p = 0.254$) groups were normally distributed. In addition, Levene's test yielded a significant value of 0.441, indicating homogeneous variances between groups. With both assumptions satisfied, the pretest data were appropriate for further analysis using an independent samples t-test under the equal variances assumed condition.

Independent Samples t-Test Pretest

After the pretest data were confirmed to meet the assumptions of normality and homogeneity of variance, the next step was to conduct an independent samples t-test to examine differences in the mean initial ability of plane geometry concept understanding between the experimental and control classes. This test was selected because the two groups were independent and the data were measured on an interval scale. The primary purpose of this analysis was to ensure that any differences in posttest learning outcomes were truly attributable to the instructional treatment rather than to differences in students' initial ability. Statistically, the test was conducted at a significance level of alpha 0.05, with the null hypothesis (H_0) stating that there was no difference in the mean initial ability between the two groups.

Table 4. Independent Samples t-Test Pretest

Independent Samples Test					
	Lavene's Test for Equality of Variances				
	F	Sig.	t	df	Sig. (2-tailed)
Equal variances assumed	0.222	0.441	-1.108	28	0.277

Based on the independent samples t-test results presented in Table 4, the t statistic was −1.108 with degrees of freedom (df = 28) and a significance value (p = 0.277). Because the p-value is greater than the 0.05 significance level, the null hypothesis cannot be rejected. In other words, statistically, there was no significant difference between the initial ability in understanding plane geometry concepts of students in the experimental and control classes.

The difference in mean pretest scores between the experimental class (M = 56.73) and the control class (M = 60.13) was only 3.40 points, which is relatively small compared with the score distributions in each group (SD=7.99 for the experimental class and SD= 8.79 for the control class). This indicates that the observed score variation was more likely due to individual differences among students than to systematic differences between groups. These results suggest that the experimental and control classes were equivalent at baseline before the treatment was implemented. This baseline equivalence is an important prerequisite in quasi-experimental research because it ensures that differences in posttest outcomes can be more validly attributed to the implementation of the Tugu Yogyakarta ethnomathematics pop-up book rather than to differences in students' initial ability.

Descriptive Analysis of the Posttest

Posttest analysis was conducted to provide a quantitative description of student's achievement in understanding plane geometry concepts after the instructional treatment was implemented. At this stage, the experimental class received instruction using the Tugu Yogyakarta ethnomathematics pop-up media, whereas the control class participated in textbook-based instruction.

Table 5. Descriptive Analysis of Posttest Results

Class	**Descriptive Analysis**			
	Mean	Std. Deviation	Minimum	Maximum
Class Experiment	80.20	4.38	72	86
Class Control	71.07	6.84	60	80

Based on Table 5, the experimental class achieved a posttest mean score of 80.20 with a standard deviation of 4.38, whereas the control class obtained a mean score of 71.07 with a standard deviation of 6.84. The mean difference of 9.13 points indicates that, descriptively, the experimental class reached a higher level of understanding of plane geometry concepts than the control class. The smaller standard deviation in the experimental class indicates more homogeneous and consistent learning outcomes. To clarify differences in the pattern of students learning improvement before and after the treatment, a comparison of pretest and posttest scores in the experimental and control classes is presented in Figure 1.

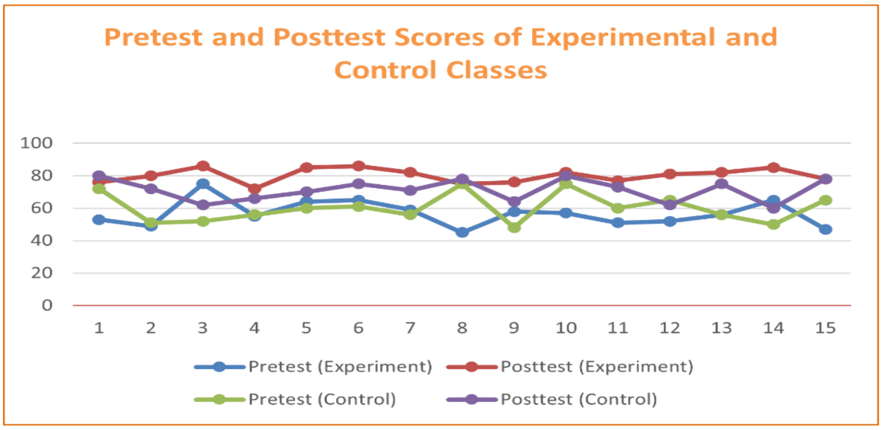

Figure 2. Comparison of Pretest and Posttest Scores

In the graph above, both classes show an increase in scores from the pretest to the posttest. However, the improvement in the experimental class appears more pronounced and more evenly distributed than in the control class. The posttest scores in the experimental class tend to be higher and more consistent, whereas the control class shows a relatively more varied improvement. This finding reinforces the descriptive results indicating that the use of the Tugu Yogyakarta ethnomathematics pop-up media had a positive effect on students understanding of plane geometry concepts, which is further examined through inferential statistical testing.

Posttest Normality and Homogeneity Test

Before conducting inferential analysis, the posttest data were examined to meet the assumptions of parametric testing. Data normality was assessed using the Shapiro–Wilk test, while homogeneity of variance was evaluated using Levene's test to ensure the validity of subsequent statistical analyses.

Table 6. Normality Test of Posttest Scores

Posttest Results	Shapiro-Wilk		
	Statistic	df	Sig.
Class Experiment	0.942	15	0.404
Class Control	0.925	15	0.232

Table 7. Levene Test Results for Posttest Variance Homogeneity

Posttest Results	Levene Statistic	df1	df2	Sig.
Based on Mean	2.987	1	28	0.095

The Shapiro-Wilk normality test results showed a significant value of 0.404 for the experimental class and 0.232 for the control class. Both values exceeded the 0.05 significance level, indicating that the posttest score distributions in both groups were normally distributed. Therefore, the normality assumptions as a prerequisite for parametric analysis were satisfied.

The homogeneity of variance test using Levene test yielded a significance value of 0.095, which was also greater than 0.05. This result indicates that the variances of posttest scores between the experimental and control classes were homogeneous. Meeting the homogeneity of variance assumption allows the use of an independent samples t-test under the equal variances assumed condition. Overall, the fulfillment of the normality and homogeneity of variance assumptions indicates that the posttest data were suitable for analysis using parametric tests. Therefore, the subsequent analysis of mean differences in posttest results between the experimental and control classes can be conducted validly, and the results can be interpreted with confidence.

Posttest t-Test

After the posttest data met the assumptions of normality and homogeneity of variance, an independent samples t-test was conducted to examine differences in the mean understanding of plane geometry concepts between the experimental and control classes after the instructional treatment was implemented. The test was performed at a significance level of α = 0.05, with the null hypothesis stating that there was no difference in the mean posttest scores between the two groups. The test results are presented in Table 8.

Table 8. Independent Samples t-test for the Posttest

Independent Samples Test									
Levene's Test for Equality of Variances									
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Equal variances assumed	2.987	0.095	4.356	28	0.000	9.13	2.10	4.83	13.43

Based on Table 8, the results showed t = 4.356 with degrees of freedom df = 28 and a significance value p = 0.000, therefore the null hypothesis was rejected. This result indicates a statistically significant difference between the posttest outcomes of the experimental and control classes. The mean difference of 9.13, with a 95% confidence interval ranging from 4.83 to 13.43, indicates that the experimental class consistently achieved higher learning outcomes than the control class. These findings indicate that the use of the Tugu Yogyakarta ethnomathematics pop-up book as a learning media significantly improved fourth-grade students' understanding of plane geometry concepts. The subsequent discussion will focus on interpreting the research findings within the context of mathematics learning theory, particularly the relationship among the ethnomathematics approach, the use of concrete visual media, and improved conceptual understanding of plane geometry among elementary students.

Discussion

This discussion aims to interpret the empirical findings of the study by linking them to theories of geometry learning and the ethnomathematics approach, as well as their implications for elementary mathematics education. The focus of the discussion is not merely on differences in learning outcomes between the experimental and control groups, but on how cultural context and students' cognitive mechanisms interact to support the development of meaningful conceptual understanding of plane geometry.

Ethnomathematics as a Conceptual Framework for Geometry Learning

The ethnomathematics approach views mathematics as a product of human activity that develops within particular social and cultural contexts (D'Ambrosio, 2001). Within this framework, mathematical concepts do not exist solely as abstract ideas but are embedded in cultural practices, artifacts, and symbols that carry meaning for a community. The findings of this study suggest that integrating the Tugu Yogyakarta as an ethnomathematics context has the potential to strengthen students understanding of plane geometry concepts, because students learn through representations that are closely connected to their experiences and cultural environment.

The role of the cultural context of Tugu Yogyakarta in this study does not lie in introducing its philosophical values in depth, but rather in its function as a familiar and concrete learning context for students. Familiarity with the cultural object helps reduce initial cognitive load, so students do not need to allocate cognitive resources to understanding an entirely new object. With reduced initial cognitive load, students can focus more on identifying and analyzing the plane geometry concepts being learned (Sweller, 2011).

Tugu Yogyakarta has a clear geometric structure, including square and triangular forms, symmetry, and proportion, which implicitly represent plane geometry concepts. When these geometric forms are learned through a cultural object context, students do not perceive them as isolated and abstract shapes, but as parts of a coherent and observable structure. Plane figures are no longer perceived as stand-alone geometric symbols, but as elements that have positions and relationships within a real object that can be directly observed. This condition helps students construct stronger conceptual meaning compared to learning that relies solely on standard plane geometry images in textbooks. This finding supports the view of Orey & Rosa (2016), who argue that ethnomathematics functions as a bridge between students' informal knowledge and formal mathematical knowledge. In this study, this bridge is realized through the role of cultural context as a meaning anchor that connects students' visual experiences with the plane geometry concepts being learned, thereby supporting meaningful learning (Bryce & Blown, 2024). Thus, cultural context does not function as a decorative element, but as an integral part of the learning process that helps students understand geometric concepts contextually.

Furthermore, the ethnomathematics approach enables a deeper meaning making process (Barton, 1996). Students do not simply memorize the characteristics of plane figures but develop conceptual understanding through identifying patterns, relationships, and geometric structures found in cultural objects (Halim & Darmayanti, 2025; Payadnya et al., 2024). However, students' engagement with the cultural context in this study operates at a contextual and representational level, rather than at an abstract philosophical level. Therefore, the effectiveness of ethnomathematics in this study primarily lies in its ability to reduce the level of abstraction in geometry concepts and to strengthen students' conceptual meaning-making. Nevertheless, these findings are not intended to claim that cultural contexts automatically improve conceptual understanding. The effectiveness of ethnomathematics depends strongly on how the cultural context is systematically integrated into instructional design (Purniati et al., 2022). In this study, the use of a pop-up book media allowed the ethnomathematics context to be presented in a structured manner and aligned with the learning objectives, thereby supporting students knowledge construction more effectively.

Cognitive Perspective: Visual Spatial Skills Representation and Students Developmental Stages

From a cognitive perspective, geometry learning requires visual spatial and representational abilities, as reflected in the strong relationship between spatial reasoning skills, including visualization and object manipulation, and the geometric reasoning abilities of students and teachers (Kyaw & Vidákovich, 2025; Schenck & Nathan, 2024). Many studies indicate that elementary students difficulties in understanding geometry are often caused by the high level of abstraction of geometric concepts and limitations in visualization ability. For example, a study examining the effects of geometry learning using augmented reality technology found that underdeveloped spatial visualization influenced students understanding of abstract geometric shapes and relationships (Nadzeri et al., 2024). In addition, a meta analytic review reported that instruction supported by visualization consistently improves mathematics learning outcomes, indicating that limited visualization is a key barrier in geometry learning (Schoenherr et al., 2024). The findings of this study suggest that the use of a pop-up book has the potential to reduce these cognitive barriers by providing concrete visual and spatial representations.

Based on Piaget cognitive development theory, children aged 7 to 11 years are in the concrete operational stage, where conceptual understanding is more effective when supported by real objects or concrete representations (Hyun et al., 2020). A pop-up book, with its three dimensional features and interactive elements, provides opportunities for students to observe, manipulate, and explore geometric shapes directly. This process enables students to gradually build connections among visual representations, mathematical language, and abstract concepts. In addition, Bruner representation theory explains that conceptual understanding develops through three modes of representation, namely enactive, iconic, and symbolic (Francis et al., 2016). An ethnomathematics based pop-up book allows these three modes to occur simultaneously. Physical interaction with the pop-up represents the enactive mode, visualization of geometric forms reflects the iconic mode, and the accompanying conceptual explanations and mathematical symbols function as the symbolic mode. The findings of this study indicate that the integration of these three representational modes contributes to deeper and more stable conceptual understanding, as reflected in the posttest results of the experimental class.

Furthermore, the lower standard deviation in the experimental class indicates that the pop-up book may facilitate more consistent understanding among students with diverse ability levels. This aligns with the view of Moyer-Packenham et al. (2014) that manipulative and visual media can help reduce cognitive gaps among students by providing alternative pathways for understanding mathematical concepts.

Integrating Ethnomathematics and Pop-Up Media in Geometry Learning

The findings of this study indicate that the effectiveness of the pop-up book media cannot be separated from the context of ethnomathematics that underlies it. The pop-up media functions as a cognitive tool that makes cultural context more concrete, while ethnomathematics provides a meaning framework that makes geometry learning relevant and meaningful for students. The interaction between these two aspects creates a learning environment that supports active and contextual knowledge construction.

The results of this study support the view that effective mathematics learning does not depend only on how content is presented, but also on how concepts are connected to students experiences, culture, and cognitive structures. In this context, the use of an ethnomathematics-based pop-up book grounded in the Tugu Yogyakarta context has the potential to strengthen students' understanding of plane geometry concepts through cognitive mechanisms that are integrated with cultural context. Nevertheless, these findings should be interpreted with caution. This study does not claim that an ethnomathematics approach combined with pop-up media will produce the same effects in all learning contexts. However, the results provide empirical evidence supporting the potential of this approach as an alternative for geometry learning in elementary school.

Although the findings are positive, this study has several limitations. The relatively small sample size and the cultural context that is specific to Tugu Yogyakarta limit the generalizability of the results. Therefore, future studies may involve larger numbers of participants, different cultural contexts, or a longitudinal research design to examine the sustainability of students conceptual understanding. Overall, these findings support the purpose of the study, namely to improve fourth-grade students' understanding of plane geometry concepts through the integration of the Tugu Yogyakarta ethnomathematics context and pop-up book media, which operate through visual-spatial cognitive mechanisms and culture-based meaning construction.

CONCLUSION

This study indicates that integrating Tugu Yogyakarta ethnomathematics through pop-up book media has strong potential to enhance elementary students' conceptual understanding of plane geometry. By connecting geometric concepts with concrete visual representations and culturally familiar contexts, learning becomes more meaningful and aligned with students' cognitive development. As a result, plane geometry is not treated merely as an abstract body of formulas, but as knowledge that is closely related to students' real-life experiences and cultural environment. From a policy and instructional perspective, these findings support the implementation of contextual, visual, and culture-based mathematics learning, in line with the principles of the Merdeka Curriculum. Teachers are encouraged to design learning experiences that integrate innovative instructional media to support students' visual–spatial abilities and promote more equitable conceptual understanding in heterogeneous classrooms.

Despite these positive findings, this study is limited by its relatively small sample size and its focus on a specific cultural context. Therefore, future research is recommended to be conducted in a more systematic manner. First, studies involving larger and more diverse samples are needed to strengthen the generalizability of the findings. Second, further research may explore ethnomathematics contexts from different cultural settings to examine the consistency of this approach across cultures. Third, longitudinal studies or investigations focusing on other learning outcomes, such as mathematical reasoning and students' attitudes toward mathematics, are suggested. Overall, this study confirms that ethnomathematics-based geometry learning supported by pop-up media has the potential to serve as an innovative alternative in elementary mathematics instruction. This approach not only strengthens students' conceptual understanding but also promotes mathematics learning that is more contextual, inclusive, and aligned with local cultural values, thereby contributing to the development of more meaningful and sustainable mathematics education.

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