Integrating Ethnomathematics and GeoGebra: A Project-Based Learning Approach to Improve Mathematical Literacy

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Abstract: Mathematical literacy—the ability to formulate, apply, and interpret mathematics in diverse contexts—is essential for addressing real-life challenges in the 21st century. However, many students struggle with this competency due to traditional procedural teaching methods that lack cultural relevance and technological integration. This study examines the impact of an Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra on students' mathematical literacy. Using a quasi-experimental design, 212 senior high school students from three accredited public schools in Karo Regency, North Sumatra, Indonesia, were divided equally into an experimental group (Ethno-PjBL with GeoGebra) and a control group (conventional instruction). Mathematical literacy assessment utilized a test based on PISA indicators. After confirming non-normal data distribution, the Mann–Whitney U test revealed a significant difference between the groups (p = 0.015), with the experimental group outperforming the control group. These results suggest that integrating cultural contexts with technology through the Ethno-PjBL model effectively enhances students' mathematical literacy—even during a brief intervention period, as demonstrated in this study.

Keywords: mathematical literacy, GeoGebra, ethnomathematics, project-based learning, quasi-experimental

INTRODUCTION

Mathematical literacy is one of the essential competencies students must possess to face the challenges of the 21st century (Muhaimin et al., 2024). It encompasses computational skills and the ability to understand, interpret, and apply mathematics in various real-life contexts. Mathematical literacy plays a vital role in everyday life, enabling individuals to apply mathematical knowledge in practical situations such as managing personal finances, interpreting data, and making informed decisions (Serin, 2023). Research indicates that low mathematical literacy leads to difficulties in problem-solving, potentially hindering participation in high-skilled jobs and exacerbating socio-economic disparities (Sitopu et al., 2023). Therefore, integrating mathematical literacy into primary and secondary education curricula is essential for improving education quality and global competitiveness (Nurmasari et al., 2023; OECD, 2018).

Globally, the 2022 Programme for International Student Assessment (PISA) survey conducted by the OECD revealed that Indonesian students' mathematical literacy remains low, with average scores significantly below the OECD average (OECD, 2023a). This finding suggests a gap between school curricula and the practical needs of everyday mathematical problem-solving. The report further highlights Indonesian students' weaknesses in reasoning, problem-solving, and applying mathematical concepts in real-life situations (OECD, 2023b). These outcomes emphasize improving mathematics teaching approaches to be more contextual, meaningful, and supportive of developing mathematical literacy.

In practice, mathematics instruction in Indonesia often relies on conventional, procedural, and mechanistic methods. Students tend to memorize formulas without understanding underlying concepts and seldom have opportunities to explore mathematics through real-world contexts. This approach significantly impedes the development of mathematical literacy (Wijaya et al., 2024). Consequently, adopting learning approaches that connect mathematics to students' real-life experiences becomes necessary, and Project-Based Learning (PjBL) offers a promising solution.

Project-Based Learning emphasizes active student engagement in solving authentic, contextual problems through projects. Research shows that this model enhances critical thinking, collaboration, and the application of mathematical concepts in daily life (Bell, 2010). However, PjBL implementation rarely incorporates students' local culture, although integrating cultural elements can strengthen students' connection to the material.

Ethnomathematics links mathematical concepts with local cultural practices. It views mathematics as a universal discipline shaped and developed through human culture. Studies have demonstrated that incorporating ethnomathematics in teaching increases students' motivation and understanding because they perceive the material as more relevant and familiar (Rosa & Orey, 2016). Combining ethnomathematics with Project-Based Learning presents a promising instructional approach. This model engages students in authentic projects and elevates local wisdom and cultural practices within mathematics learning. Through this approach, students learn mathematics from their environment, fostering a stronger internalization of concepts (Maulina et al., 2024).

Despite these benefits, students often need visual tools to understand mathematical ideas better. GeoGebra, an interactive software, supports dynamic visualization and has proven effective in improving comprehension, particularly in geometry and algebra (Zengin et al., 2012). Integrating GeoGebra into the Ethno-Project-Based Learning model represents an innovative advancement in mathematics education. GeoGebra enables students to explore culture-based mathematical projects visually and interactively, helping them grasp the relationship between mathematics, culture, and its applications in daily life. This approach could strengthen mathematical literacy across conceptual, procedural, and applicative dimensions.

Research on the combined use of Ethno-PjBL and GeoGebra in Indonesian mathematics education is limited. This study aims to fill that gap by investigating how this integrated model influences students' mathematical literacy, offering a culturally responsive and technologically enriched approach to improve learning outcomes. This study aims to inform curriculum development and foster innovative instructional strategies that address current educational challenges.

However, implementing the Ethno-Project-Based Learning model with GeoGebra support poses challenges, including teacher readiness to integrate local culture, project-based methods, and digital technology simultaneously. Hence, teacher training and support are critical for practical application. This model offers novelty in mathematics education by integrating local cultural elements through ethnomathematics, project-based learning strategies, and GeoGebra's visual technology. The combination of these three approaches has been underexplored, especially in Indonesia, indicating its significant potential as a leading model to enhance students' mathematical literacy.

Considering this approach's urgency, challenges, and potential, this study on using an Ethno-Project-Based Learning model supported by GeoGebra remains timely and important. Based on the discussion above, this study addresses the following research question: "Is there a difference in mathematical literacy between students who participate in project-based learning using GeoGebra and those who follow traditional learning models?" The study aims to improve students' literacy and enrich research and practical knowledge related to contextual, relevant, and innovative mathematics education in Indonesia.

LITERATURE REVIEW

Mathematical Literacy Skills

Mathematical literacy refers to an individual's ability to understand, use, and interpret mathematical concepts and procedures in various real-life contexts (OECD, 2019b). Mathematical literacy encompasses the ability to formulate, employ, and interpret mathematics across different situations, solve problems, reason logically, communicate, and explain mathematics in everyday and shared contexts.

Mathematical literacy through three key processes: formulate, employ, and interpret (OECD, 2019a). The formulation process involves translating real-world problems into mathematical form, including recognizing the mathematical aspects of a given context. In the employ process, students actively employ mathematical knowledge and procedures to solve mathematically formulated problems. Lastly, the interpretation process involves understanding and interpreting mathematical outcomes within real-world contexts, including the ability to evaluate and communicate the results logically.

Various factors influence mathematical literacy, including learning motivation, teaching approaches, and students' cognitive readiness. Research by Hamdiyanti et al. (2023) shows that students with high intrinsic motivation tend to possess stronger mathematical literacy skills. Meanwhile, Yusuf et al. (2024) highlight the role of cognitive styles in shaping students' thinking processes when formulating and interpreting mathematical problems. Educators also play a critical role in encouraging reflective thinking and promoting contextual applications of mathematics in the classroom.

This study employs three primary indicators of mathematical literacy: formulating, employing, and interpreting. These indicators encompass students' abilities to identify, apply, and comprehend mathematical concepts in various real-world contexts. The indicators aim to assess students' mathematical literacy skills comprehensively.

Project-Based Learning Model

Project-Based Learning (PjBL) is an instructional model that positions students as active participants in their learning by engaging them in real and meaningful projects (Bell, 2010). Through PjBL, students do not merely receive information passively. However, they are encouraged to develop critical thinking, collaboration, and problem-solving skills by working on projects that are relevant to real-world contexts (Thomas, 2000). PjBL encourages students to conduct in-depth investigations, plan, implement, and reflect on their learning processes individually and in groups.

According to Holm (2011), one of the key strengths of PjBL lies in its ability to integrate various disciplines within a single project, enabling students to perceive the interconnections between concepts and their applications in everyday life. Maysarah (2015) found that project-based learning can enhance students' mathematical communication skills and creativity. Students taught using a project-based learning model demonstrate higher levels of mathematical literacy than those taught through conventional instruction (Maysarah et al., 2023). Implementing PjBL typically begins with presenting a problem or challenge that students must address through a specific project. Students then design a work plan, collect data, and produce a final product, which is later presented to the teacher and peers (Bell, 2010). This process involves collaborative Learning and the development of soft skills such as responsibility, time management, and effective communication. The final product serves as tangible evidence of students' competence. Nevertheless, PjBL is not without its challenges. According to Thomas (2000), teachers must manage time and resources effectively while guiding students to remain focused and avoid irrelevant activities. The learning environment and student readiness are also crucial factors that determine the success of PjBL. However, PjBL can be an effective and engaging learning model when implemented appropriately.

Research by Krajcik & Blumenfeld (2006) shows that the PjBL model provides a robust framework for integrating multiple disciplines and supports contextual Learning focused on developing 21st-century skills such as creativity and problem-solving. Furthermore, Larmer et al. (2015) emphasized that effective PjBL implementation requires thorough planning, systematic execution, and in-depth reflection and evaluation by students and teachers. The study also highlights the importance of the teacher's role as a facilitator throughout the learning process.

The fundamental principles in the development of instructional models are, (1) *Syntax*, referring to the systematic steps of the learning process; (2) *Reaction Principles*, concerning how the teacher responds to students' behaviors to guide them toward learning objectives; (3) *Social System*, referring to the relational structure between teacher and students during instruction; (4) *Support System*, which includes tools, infrastructure, and resources that support model implementation; and (5) *Instructional and Nurturant Effects*, which encompass both the direct learning outcomes and indirect results such as the development of attitudes, values, or social skills (Joyce et al., 2009). These principles serve as a conceptual framework for designing practical and student-centered instruction.

The Project-Based Learning (PjBL) model positions students at the center of the learning process by engaging in authentic and meaningful projects. This study's PARR (Plan, Action, Report, Reward) syntax provides a systematic framework for implementing PjBL, from project planning to recognizing students' achievements. Applying this syntax makes the learning process more structured, effectively promoting student engagement and optimizing competency attainment.

Ethnomathematics

Ethnomathematics studies the relationship between mathematics and culture, emphasizing how different cultural groups develop and utilize mathematical concepts in their daily lives (D'Ambrosio, 2006). Ethnomathematics is a concept first introduced by D'Ambrosio (1999), who described it as a form of mathematical literacy that evolves within specific cultural contexts and recognizes that every community possesses unique ways of solving problems involving mathematical ideas, such as measurement, patterns or number systems. Thus, this approach highlights mathematics education's cognitive aspects and social and cultural dimensions.

According to D'Ambrosio (2001), ethnomathematics is not merely the study of traditional or local mathematics but an acknowledgment of diverse global mathematical thinking. Furthermore, ethnomathematics plays a role in preserving cultural heritage and fostering students' cultural identity through mathematics instruction (Powell & Frankenstein, 1997). Research by Sari et al. (2024) and Wulandari et al. (2024) indicates that integrating ethnomathematics into education can enhance students' understanding of mathematical concepts by connecting the material to local cultural contexts. A study by Mulenga & Folokwe (2024) demonstrates that teaching geometry through local cultural practices can deepen conceptual understanding, preserve cultural traditions, and promote an inclusive approach to mathematics education.

One of the main strengths of the ethnomathematical approach is its ability to bridge the gap between formal mathematics and the local knowledge systems students possess. This approach is highly effective in helping students from indigenous communities grasp mathematical concepts through familiar cultural practices (Nur et al., 2023). Such an approach increases student engagement in learning and supports preserving local culture. Moreover, such an approach enriches the learning process by embedding local values that shape students' character and attitudes toward knowledge.

Beyond conceptual understanding, ethnomathematics also fosters critical thinking and problem-solving skills. Ethnomathematics-based mathematics instruction can enhance students' ability to creatively analyze and solve mathematical problems (Imswatama, 2018). Teachers encourage students to memorize formulas and reflect on how they apply mathematical concepts within their cultural contexts. Such an approach provides a strong foundation for developing a more holistic and functional form of mathematical literacy.

In conclusion, ethnomathematics is an innovative approach significantly contributing to mathematics education. By emphasizing cultural relevance and local context, this approach strengthens students' conceptual understanding while enriching their cultural and social values. Therefore, integrating ethnomathematics into the mathematics curriculum should be continuously promoted as a strategic effort to improve the quality of education in multicultural societies. The cultural context highlighted in this study is the Karo culture, originating from North Sumatra Province, Indonesia.

GeoGebra

GeoGebra is an open-source dynamic mathematics software that integrates geometry, algebra, calculus, and statistics into a single interactive platform. Users can access it both online and offline, and it supports active and constructivist learning. Through interactive graphics, GeoGebra enables users to create mathematical visualizations that help students meaningfully connect visual and symbolic representations (Kovács et al., 2023).

Initially developed by Markus Hohenwarter, GeoGebra has been widely adopted across the globe in mathematics education, from primary schools to university-level instruction. Due to its free accessibility, user-friendly interface, and multilingual support, GeoGebra has become a popular tool in technology-enhanced mathematics education (Awaji et al., 2025).

GeoGebra has been proven effective in enhancing mathematical comprehension, problem-solving skills, and student motivation. A study by Awaji et al. (2025), which reviewed two decades of GeoGebra-related publications, identified three main areas of application: as a teaching aid in geometry, a tool for integrating technology into Learning, and a means to improve mathematics achievement. The growing body of research on GeoGebra highlights its significant influence on mathematics education (Kovács et al., 2023).

In geometry instruction, GeoGebra enables students and teachers to visualize abstract ideas through interactive exploration, fostering deeper Learning and encouraging discovery-based approaches (Triet et al., 2024). Combined with the 5E instructional model, its use significantly improved students' grasp of the area formula for trapezoids (Triet et al., 2024). The result demonstrates how technology-enhanced methods can boost engagement and understanding in math classrooms.

GeoGebra is an open-source dynamic mathematics software that provides an interactive platform for the real-time exploration and visualization of mathematical concepts, accessible online and offline. This software supports a more active and constructivist learning process by utilizing visual media to facilitate understanding of abstract concepts. The study explores geometric transformations using various GeoGebra features to deepen students' conceptual understanding.

METHOD

Research Design

This study employed a quantitative approach using a quasi-experimental research design. Quasi-experimental research involves manipulating the independent variable without randomly assigning participants into groups (Jhangiani et al., 2019). The design was appropriate to examine the effect of the Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra on students' mathematical literacy. This approach suits researchers without complete control over the independent variable, such as randomizing subjects (Creswell, 2012).

This study employed a quasi-experimental nonequivalent control group pre-test and post-test design. The researcher non-randomly assigned participants to the experimental and control groups and measured their performance before and after the intervention (Creswell, 2012; Fraenkel et al., 2012; Jhangiani et al., 2019). The researcher purposively selected two groups: the experimental group received the Ethno-PjBL model supported by GeoGebra (X), while the control group followed conventional instruction. The researcher assessed students' mathematical literacy using pre-tests and post-tests. O_1 and O_2 correspond to the pre-test and post-test of the experimental group, whereas O_3 and O_4 correspond to the pre-test and post-test of the control group. Table 1 summarizes the research design.

Group	Pre-test	Treatment	Post-test
Experimental	O_1	X	O_2
Control	O_3	—	O_4

Table 1: Research Design

Population and Sample

The study population consisted of all students from public senior high schools (SMAN) across Karo Regency, North Sumatra Province, Indonesia. The study used cluster random sampling by dividing the population into natural clusters (i.e., schools) and randomly selecting several clusters as the sample (Creswell, 2012; Lohr, 2019). The study grouped accredited public high schools (SMAN) within the regency into clusters. The team randomly selected schools with accreditation A to ensure comparable education quality among the chosen clusters. The total sample comprised 212 students distributed as shown in Table 2:

School	Experimental Group (Students)	Control Group (Students)
SMAN 1 Kabanjahe	36	35
SMAN 1 Berastagi	34	36
SMAN 2 Kabanjahe	36	35
Total	106	106

Table 2: Sample Distribution

Data Collection

The instructional process comprised five modules, each delivered over five 45-minute sessions. Each module focused on a geometric transformation and included a project-based task involving the design of batik motifs inspired by the Karo cultural heritage: module 1 emphasized translation, module 2 reflection, module 3 rotation, module 4 dilation, and module 5 composition of transformations. The study implemented the modules following the Ethno-Project-Based Learning (Ethno-PjBL) framework, which follows the PARR cycle. The cycle begins with Plan, in which instructors design learning activities and project assignments; continues with Action, where students actively engage in learning and complete the projects; proceeds with Report, in which students present outcomes and reflect on their experiences; and concludes with Reward, providing feedback and incentives to enhance motivation. Student projects contributed 40% of the final course grade, with the remaining 60% coming from quizzes, assignments, and class participation.

The primary instrument used in this study was a mathematical literacy test consisting of four items, each encompassing the three core PISA indicators: Formulate, Employ, and Interpret (OECD, 2023). The researcher independently developed the items, guided by the PISA mathematical literacy framework, and adapted them to align with the local cultural context and school curriculum. The instrument met both validity and reliability standards, with a Cronbach's Alpha coefficient exceeding 0.7 indicating acceptable reliability.

Data Analysis

Quantitative data analysis employed inferential statistical tests to evaluate the hypotheses. Normality and homogeneity of variances were assessed using the Shapiro-Wilk and Levene's tests, respectively, following established protocols (Field, 2018). Because the data violated the normality and homogeneity assumptions, the study applied the Mann–Whitney U test to compare the groups (Pallant, 2020; Saragih, 2015). All analyses employed SPSS software, with a significance level of 5% ($\alpha = 0.05$) set as the criterion for interpreting the results (Larson-Hall, 2016).

In addition to other methods, this study applies a descriptive quantitative approach to evaluate students' and teachers' responses to implementing the Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra in mathematics education. The researchers collect data using a 4-point Likert scale questionnaire focusing on learning interest, motivation, and perceived usefulness. They analyze the data by calculating students' and teachers' mean response scores for each aspect.

The research hypothesis tested whether mathematical literacy significantly differed between the two groups exposed to different instructional models. The null hypothesis (H_0) stated that no significant difference existed between students taught using the Ethno-Project-Based Learning model supported by GeoGebra and those receiving conventional instruction. Conversely, the alternative hypothesis (H_1) posited a significant difference in mathematical literacy between the two groups.

RESULTS

The validity test results indicate that all instrument items have correlation coefficients exceeding the critical r-table value, confirming that all items are valid and appropriate for use in this study. Pearson's Product-Moment correlation assessed the validity by comparing the calculated correlation coefficient (r-calculated) with the critical r-table value. An item is valid if r-calculated > r-table at a specified significance level (e.g., $\alpha = 0.05$). The analysis shows that all instrument items demonstrated r-calculated values greater than r-table, confirming their validity and suitability for this research (Arikunto, 2013; Creswell, 2012). The summary of the validity test results is presented in Table 3 below:

Item Number	r-calculated	r-table	Validity
1a	0.829	0.381	Valid
1b	0.867		Valid
1c	0.732		Valid
2a	0.683		Valid
2b	0.848		Valid
2c	0.489		Valid

Item Number	r-calculated	r-table	Validity
3a	0.834		Valid
3b	0.748		Valid
3c	0.682		Valid
4a	0.858		Valid
4b	0.816		Valid
4c	0.531		Valid

Table 3: Summary of Test Instrument Validity Results

The table above shows that the item-total correlation coefficients (r values) range from 0.489 to 0.867, all exceeding the critical r value of 0.381 at the 5% significance level with a sample size of 27 students. The findings demonstrate that each test item significantly correlates with the total score, empirically confirming the instrument's construct validity. The following table presents the reliability test results for the mathematical literacy instrument:

Case Processing Summary			
		N	%
Cases	Valid	27	100.0
	Excluded[a]	0	0.0
	Total	27	100.0
a. Listwise deletion based on all variables in the procedure.			
Reliability Statistics			
Cronbach's Alpha		N of Items	
0.924		12	

Table 4: Summary of Test Reliability Results

The analysis shows that Cronbach's Alpha coefficient was 0.924, obtained from 12 test items with 27 valid respondents. This value far exceeds the minimum recommended reliability threshold of 0.70 (Nunnally & Bernstein, 1994), demonstrating that the instrument is highly reliable and allows researchers to use it in this study confidently. Therefore, the mathematical literacy test instrument proves reliable, with each test item exhibiting strong internal consistency in measuring students' mathematical literacy ability. After establishing the reliability of the mathematical literacy test instrument, the researchers analyzed the pre-test and post-test results to measure students' mathematical literacy skills in both the experimental and control groups.

Group	Pre-Test	Post-Test	N-Gain Score
Experimental	34	82	0.72
Control	38	78	0.63

Table 5. Average Scores of Students' Mathematical Literacy Skills

Based on the table, the average pre-test score of students in the experimental class was 34, which increased to 82 on the post-test, resulting in an N-Gain score of 0.72, categorized as high. In comparison, the control class increased from 38 to 78, with an N-Gain score of 0.63, falling into the medium–high category. These results indicate that the learning intervention implemented in the experimental class improved students' mathematical literacy more effectively than the conventional approach used in the control class.

The N-Gain scores obtained from the experimental and control groups were analyzed to assess improvements in mathematical literacy. The study employed N-Gain scores instead of post-test scores alone. N-Gain provides a more accurate measure of students' improvement by accounting for differences in pre-test performance (Hake, 1998). The study then conducted normality tests to determine whether the N-Gain scores from both groups followed a normal distribution and employed two methods for the tests: the Kolmogorov–Smirnov and Shapiro–Wilk tests. The decision was primarily based on the significance value (Sig.) from the Shapiro-Wilk test, as the sample size exceeded 50 (Ghasemi & Zahediasl, 2012). The following table presents the results of the normality tests:

Group	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
N-Gain Experimental Class	0.179	106	0.000	0.926	106	0.000
N-Gain Control Class	0.119	106	0.001	0.934	106	0.000
a. Lilliefors Significance Correction						

Table 6: Normality Test Results

The results of the normality tests using Kolmogorov–Smirnov and Shapiro–Wilk indicate that the N-Gain scores for both the experimental and control groups do not follow a normal distribution. The significance values were $p = 0.000$ for the experimental group and $p = 0.001 / 0.000$ for the control group. The data did not follow a normal distribution because all significance values were below 0.05.

Test of Homogeneity of Variances			
N-Gain Score			
Levene Statistic	df1	df2	Sig.
38.105	1	210	0.000

Table 7: Homogeneity of Variance Test

The Levene's test for homogeneity of variances on the N-Gain scores yielded a statistic of 38.105 with a significance value of 0.000 (< 0.05), indicating that the variances between the experimental and control groups were not homogeneous. Because both the normality and homogeneity assumptions did not hold, the study conducted hypothesis testing using a non-parametric test, specifically the Mann–Whitney U test (Ghasemi & Zahediasl, 2012; Pallant, 2020), which does not require normally distributed or homogenous data.

Test Statistics	Value
Mann-Whitney U	4529.000
Wilcoxon W	10200.000
Z	-2.440
Asymp. Sig. (2-tailed)	0.015

Table 8. Mann–Whitney U Test Result

The Mann–Whitney U test examined the difference in N-Gain scores between the experimental and control groups. The test produced a U value of 4529.000 and a significance level of $p = 0.015$. Since $p < 0.05$, the difference between the two groups is statistically significant. This finding confirms that the learning intervention in the experimental group had a significantly greater impact on improving students' learning outcomes than the control group. The conclusion is that a statistically significant difference exists between the post-test scores of students in the experimental and control groups. Hence, reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1). These results support the conclusion that the Ethno-Project-Based Learning model assisted by GeoGebra is more efficacious in improving students' mathematical literacy skills than conventional learning models.

After implementing the Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra, we collected student and teacher responses using a questionnaire that evaluated three aspects: interest in the learning process, motivation towards learning, and perceived usefulness of the learning activities.

Aspect Evaluated	Average Student Response Score	Average Teacher Response Score
Interest in the learning process	3.61	3.80
Motivation towards learning	3.62	3.67
Perceived usefulness	3.58	3.75
Overall Average Score	3.60	3.74

Table 9: Presents the Average Scores from Students and Teachers

Students reported that the Ethno-PjBL modules supported by GeoGebra powerfully captured their interest, with an average score of 3.61, while teachers rated student interest slightly higher at 3.80. Many students explained that designing batik motifs inspired by the Karo cultural heritage made mathematics more tangible and relevant. Students felt curious and engaged by connecting abstract geometric transformations to culturally meaningful patterns throughout the learning activities.

Motivation scores were similarly high, with students scoring 3.62 and teachers 3.67. Students indicated that combining collaborative projects, interactive GeoGebra tools, and culturally relevant tasks encouraged them to persist in solving mathematical problems and completing projects thoroughly. Teachers observed increased participation, initiative, and enthusiasm, suggesting that the Ethno-PjBL approach effectively sustained student engagement and promoted active learning.

Regarding perceived usefulness, students rated the learning activities at 3.58, while teachers provided a slightly higher score of 3.75. Both groups agreed that the modules were relevant and beneficial for enhancing mathematical understanding. Teachers highlighted that students could apply geometric transformations meaningfully within real-world and cultural contexts, demonstrating that integrating culture, technology, and project-based tasks fostered both learning effectiveness and appreciation of mathematics.

Overall, the feedback indicates that the Ethno-PjBL model supported by GeoGebra received strong acceptance and motivated students to perform better by connecting mathematics to their culture, providing hands-on problem-solving experiences, and fostering a stimulating and meaningful learning environment.

DISCUSSION

The results of this study indicate a significant difference in mathematical literacy skills between students who participated in Learning using the Ethno-Project-Based Learning (Ethno-PjBL) model assisted by GeoGebra and those who experienced conventional learning methods. The Mann–Whitney U test supports this finding, yielding a significance value of 0.015 (< 0.05), which leads to rejecting the null hypothesis and accepting the alternative hypothesis. Therefore, the Ethno-PjBL model is proven more effective in enhancing students' mathematical literacy than traditional instructional approaches.

These learning activities clearly reflect the three core dimensions of mathematical literacy defined by the OECD (2019a): formulating, employing, and interpreting. In the formulating phase, students translated traditional cultural patterns into mathematical problems by identifying geometric elements and abstracting them into formal models. In the employing phase, students applied mathematical concepts using GeoGebra, such as transformation techniques (translation, reflection, rotation), to explore and analyze the patterns. Finally, during the interpreting phase, students connected their mathematical findings back to the cultural context, demonstrating an ability to explain their results' significance mathematically and culturally. The figure below presents a more detailed analysis of students' mathematical literacy based on individual indicators.

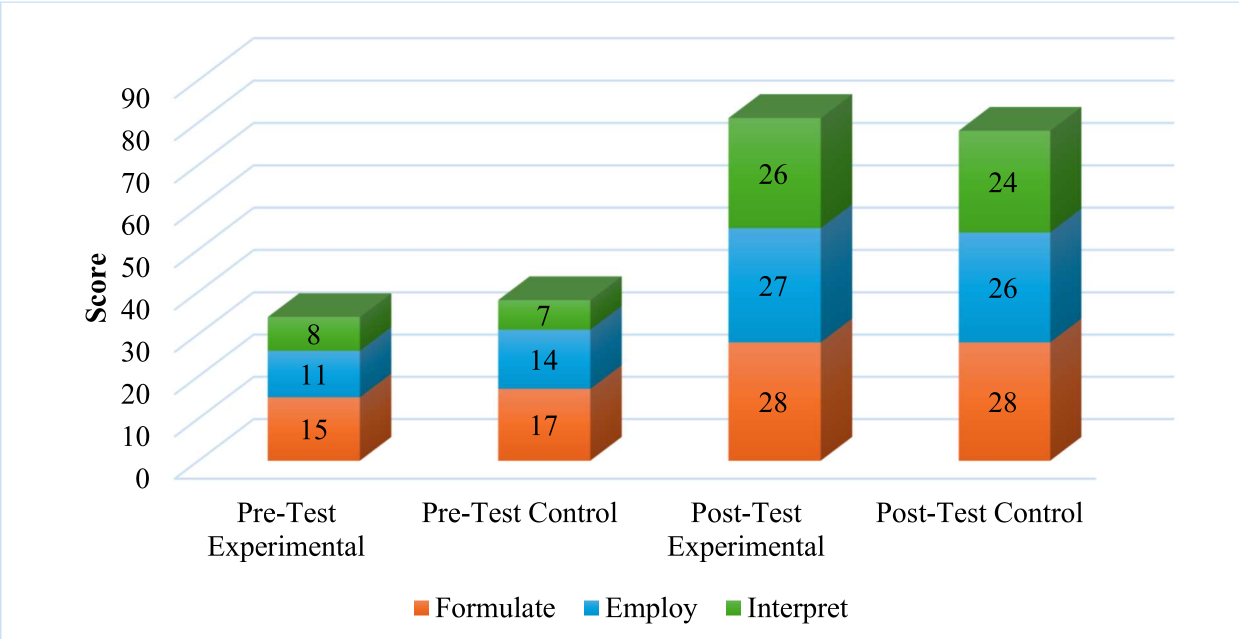

Figure 1. Average Scores of Students' Mathematical Literacy Skills by Indicator

The figure illustrates students' average scores in three components of mathematical literacy: Formulate, Employ, and Interpret, measured during the pre-test and post-test in both experimental and control groups. During the pre-test, the highest average scores appeared in the *Formulate* component, with 15 in the experimental group and 17 in the control group. The *Employ* scores were moderate (11 in the experimental group and 14 in the control group), while the *Interpret* component showed the lowest averages: 8 and 7, respectively. Overall, these results suggest that both groups had relatively comparable initial abilities, with the control group slightly ahead in *Formulate* and *Employ*, and the experimental group slightly stronger in *Interpret*.

After the intervention, all components showed substantial improvement in both groups, with greater gains in the experimental class. The *Formulate* component increased to 28 in both groups, while the *Employ* and *Interpret* components reached 27 and 26 in the experimental group, respectively, compared to 26 and 24 in the control group. Although *Formulate* improved equally, the experimental group demonstrated greater gains in *Employ* and *Interpret*. This finding suggests that the instructional approach applied in the experimental group was particularly effective in enhancing students' higher-order thinking skills compared to the conventional method used in the control group.

Ethnomathematics offers a meaningful bridge between students' cultural heritage and formal mathematics instruction. Students can interpret mathematical content through familiar representations by incorporating traditional patterns and local cultural contexts into learning activities. This relevance enriches the learning experience and affirms students' identities, fostering a stronger connection between their culture and mathematical knowledge. Using culturally rooted problems in the project-based model supports contextual Learning and encourages deeper engagement with mathematical concepts.

The strength of the Ethno-PjBL model lies in its integration of cultural context (ethnomathematics) with a project-based learning approach, encouraging students to construct their understanding actively. During the planning phase, students design projects based on contextual problems related to local culture, fostering strong initial engagement. This phase significantly activates prior knowledge and links mathematical concepts to real-life experiences (Sriraman & English, 2010). In the action phase, students engage in exploratory activities using GeoGebra, which enables dynamic visualization of mathematical concepts. GeoGebra increases students' engagement in Learning and helps them construct more accurate mathematical representations. This observation aligns with findings from previous studies, which emphasize that integrating technology into mathematics education strengthens mathematical literacy and deepens students' understanding of fundamental concepts (Zbiek et al., 2007).

The reporting phase in the Ethno-PjBL model encourages students to communicate their project results through presentations or written reports. This activity corresponds with the communication and reflection components of mathematical literacy outlined by OECD (2019a), which states that mathematically literate students can express mathematical ideas in various forms. Students in the experimental group improved their abilities, as reflected in their higher average post-test ranks compared to the control group.

Furthermore, the reward phase is positive reinforcement, fostering students' intrinsic motivation. Social constructivist learning theory posits that meaningful Learning occurs through social interaction, collaboration, and reinforcement (Vygotsky, 1978). Recognizing students' project outcomes makes learning more enjoyable and meaningful, enhancing engagement and achievement. These findings are consistent with prior research by Nugraheni et al. (2021), which showed that project-based Learning with cultural contexts can improve students' literacy skills and critical thinking abilities. Similarly, Surya & Sabandar (2020) found that project-based Learning combined with digital technology such as GeoGebra effectively enhances mathematical achievement and problem-solving skills.

GeoGebra provides students dynamic visual tools that transform abstract mathematical ideas into interactive experiences. In this study, students used GeoGebra to explore geometric transformations such as translation, reflection, and rotation embedded in traditional motifs. These visualizations facilitated a better understanding of spatial relationships and transformation properties. The real-time manipulation of objects in GeoGebra allows students to observe mathematical patterns, test hypotheses, and draw conclusions independently—skills essential for developing mathematical literacy.

The course included five student projects in which students created Karo-inspired batik motifs using GeoGebra. Project 1 focused on translation, enabling students to produce repeated geometric patterns without altering shape or size. Project 2 applied reflection to create symmetrical designs across vertical and horizontal axes. Project 3 involved rotation, arranging motifs around fixed points to explore orientation changes. Project 4 utilized dilation and varying motif sizes while maintaining proportions. Project 5 integrated all four transformations into a comprehensive final motif reflecting cultural aesthetics and geometric principles. These projects allowed students to formulate mathematical problems, employ GeoGebra tools, and interpret solutions in real-world and cultural contexts, fostering all three dimensions of mathematical literacy while enhancing motivation, engagement, and appreciation of local heritage.

Below is an example of a student project developed using the Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra. The project integrates cultural heritage into mathematics education by applying geometric transformation concepts to traditional motifs. By leveraging GeoGebra's dynamic tools, students actively investigated and visualized mathematical ideas, such as translation and reflection, within culturally significant contexts. The study classifies these activities according to the three core dimensions of mathematical literacy defined by the OECD (2019a): *formulating* (selecting and modeling geometric motifs from the Siwaluh Jabu house, such as triangles, rhombuses, and zigzag patterns), *employing* (applying translation and reflection to replicate patterns while preserving shape, size, and orientation), and interpreting (analyzing and explaining the results within cultural contexts, understanding the connection between mathematics and heritage). This approach strengthens students' understanding of geometric principles and their connection to local culture, making learning more engaging and meaningful.

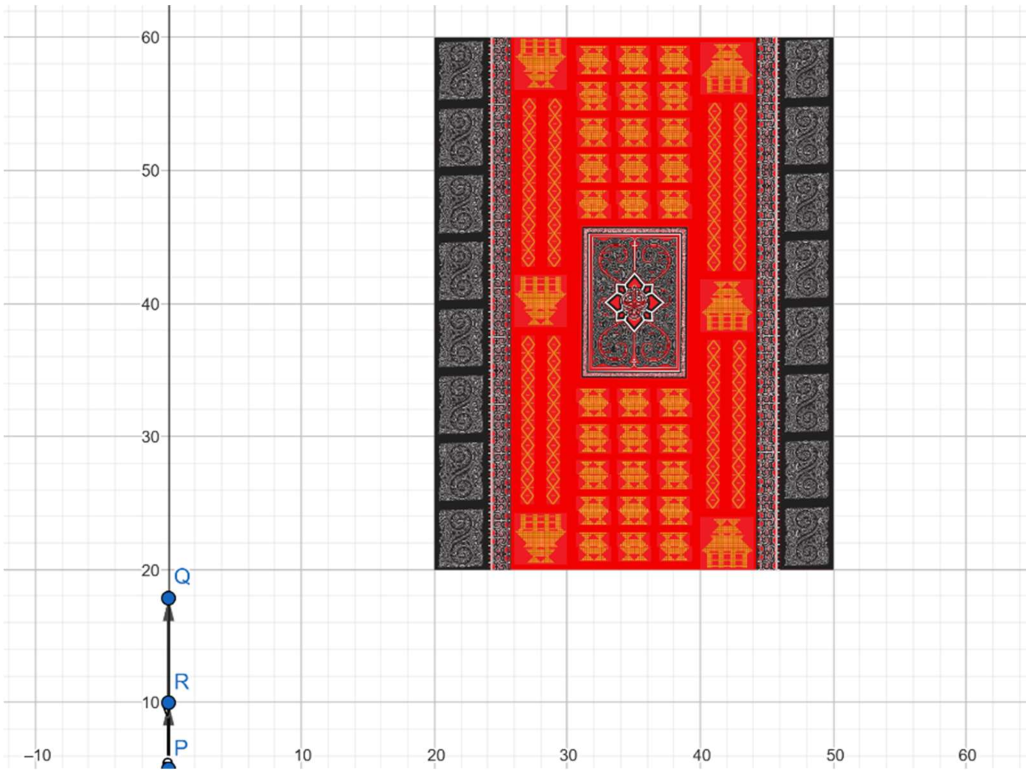

Figure 2: Student Project Output: Applying GeoGebra to Translation and Reflection

The student project illustrates how GeoGebra represents traditional architectural elements of the Karo ethnic group's Siwaluh Jabu house through geometric transformations. Students selected geometric motifs found on the house—such as triangles, rhombuses, and zigzag patterns—as the basis for applying the concepts of translation and reflection. This project demonstrates that mathematics instruction should not be separated from culture but can integrate meaningfully with rich, contextual local values.

In their diagrams, students modeled decorative elements located on the walls and roof frames of the Siwaluh Jabu, which exhibit horizontally repeating patterns. They recreated these patterns in GeoGebra and applied the concept of translation by shifting the motifs along specific vectors. Students demonstrated that the same motif could repeat consistently through translation without altering its shape, size, or orientation. This approach reinforced their understanding of translation as an isometric transformation that preserves the essential properties of geometric figures.

Beyond translation, students also applied reflection to specific symmetrical components of the traditional house, particularly the ornaments on the left and right sides of the structure. They performed reflections across vertical and horizontal axes, which correspond with the architectural symmetry of the building. Students used GeoGebra's tools to illustrate how a pattern on one side of the house reflects to produce a mirror image on the opposite side, providing a clear visual understanding of geometric reflection. This project deepened students' comprehension of geometric transformations and enriched their learning experience by incorporating a culturally responsive approach. When students explored cultural artifacts like the Siwaluh Jabu house, they viewed mathematics as an integral part of real life. The relevance of the content to their cultural background enhanced their motivation and engagement, highlighting how contextual and culture-based learning bridges academic concepts and local identity.

Overall, the student-generated diagrams provide compelling evidence of how integrating GeoGebra with cultural objects such as the Siwaluh Jabu house can enhance the quality of mathematics education. Students gained technical mastery of geometric concepts like translation and reflection and a meaningful understanding of their real-world applications. Moreover, the project fostered cultural awareness and appreciation, helping students connect mathematics with their heritage. Such an approach positions mathematics as not an abstract discipline but a dynamic and relevant body of knowledge.

Integrating cultural elements with digital tools enhanced students' intrinsic motivation. Students reported that representing their cultural heritage within mathematical tasks made the learning experience more meaningful and personally relevant. Interactive technology empowered students to take greater control of their learning, which increased their engagement and sustained interest. The Ethno-Project-Based Learning (Ethno-PjBL) model promoted collaboration through culturally grounded projects, making students feel more connected to the content and motivated to persist when solving complex problems. These results indicate that the model effectively fosters deeper learning and sustained motivation.

Teachers observed a marked increase in student enthusiasm and active participation during lessons that utilized the Ethno-PjBL approach. They noted improved student communication and cooperation, contributing to a positive classroom environment conducive to learning. Furthermore, teachers recognized that incorporating local cultural content helped demystify abstract mathematical concepts, making them more accessible and relevant to students.

Implementing the Ethno-PjBL model supported by GeoGebra significantly improved students' mathematical literacy. Beyond cognitive gains, this approach also enhanced student motivation and interest and teacher engagement with the instructional process. This study demonstrates the potential of culturally responsive pedagogy and digital tools to improve learning outcomes and learner motivation in mathematics education.

Overall, this study demonstrates that the Ethno-Project-Based Learning (Ethno-PjBL) model supported by GeoGebra effectively enhances students' mathematical literacy in a contextual and meaningful manner. The model integrates culture, technology, and collaboration within a structured learning sequence grounded in constructivist and sociocultural theories, providing an innovative approach for 21st-century mathematics education. Students formulate mathematical problems, employ appropriate strategies and tools such as GeoGebra, and interpret solutions in real-world and cultural contexts. Feedback from students and teachers indicated that integrating Karo cultural motifs with interactive projects increased interest, motivation, and engagement, supporting the meaningfulness of the learning activities. By fostering all three dimensions of mathematical literacy defined by the OECD (2019a): formulating, employing, and interpreting, this study positions its findings clearly within international mathematics education standards. It emphasizes their relevance and potential for broader application.

CONCLUSIONS

The data analysis and discussion confirm that implementing the Ethno-Project-Based Learning (Ethno-PjBL) model assisted by GeoGebra significantly enhances students' mathematical literacy skills. The Mann–Whitney U test supports this conclusion, yielding a significance value of 0.015 (< 0.05), which indicates a statistically significant difference in learning outcomes between students taught with the Ethno-PjBL model using GeoGebra and those who received conventional instruction. The higher mean rank of the experimental group suggests that this approach effectively encourages students to understand better, interpret, and apply mathematical concepts in real-life contexts. The phases of the Ethno-PjBL model—plan, action, report, and reward—have proven effective in fostering a contextual, meaningful, and participatory learning process.

These findings encourage educators to actively integrate the Ethno-PjBL model supported by GeoGebra into mathematics teaching. This model enhances mathematical literacy and enriches students' learning experiences by blending local culture with interactive technology. For schools and education policymakers, this study serves as a valuable reference for developing instructional policies that prioritize project-based, digital, and culturally relevant learning strategies. Moreover, this research paves the way for further advancements in technology-enhanced and ethnomathematics-informed mathematics education.

However, this study has certain limitations. It was conducted only in schools with excellent accreditation status, which may limit the generalizability of the findings to institutions with different educational conditions. Additionally, the research focused primarily on the cognitive domain—specifically mathematical literacy—without addressing students' affective and social aspects, which are also crucial in project-based Learning. Future studies are encouraged to involve schools with varying accreditation levels and examine the broader impact of the Ethno-PjBL model on other learning dimensions, such as collaboration, creativity, and student attitudes.

Beyond its impact on mathematical literacy scores, the Ethno-PjBL model with GeoGebra enriched students' learning experiences. Combining cultural elements and technology fostered a deeper engagement, strengthened students' conceptual understanding, and promoted a stronger connection between mathematics and students' identities. These findings highlight the potential of culturally responsive, technology-supported learning models for 21st-century mathematics education.

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APPENDIX

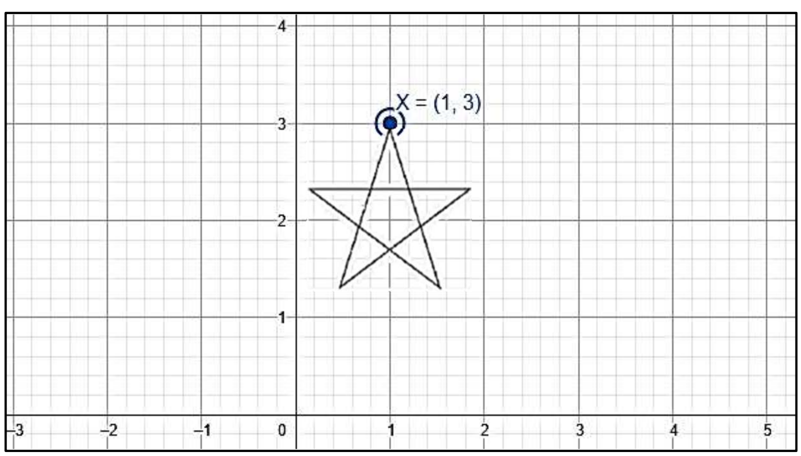
Pre-Test and Post-Test Items on Mathematical Literacy Ability

Grade	: 11th Grade Senior High School
Time Allocation	: 90 minutes
Topic	: Geometric Transformations

Instructions:

a. Fill in personal information correctly on the provided answer sheet.
b. Solve each question using complete and detailed steps on the answer sheet provided.
c. Write answers clearly and neatly using a pen.
d. Do not access notebooks or other learning resources during the test.
e. Collaboration or discussion with other students is strictly prohibited.

1. A batik artisan intends to create a uis fabric with a "tupak salah silima-lima" motif, with one of the peak points X located on the Cartesian coordinate system, as shown in the figure below.

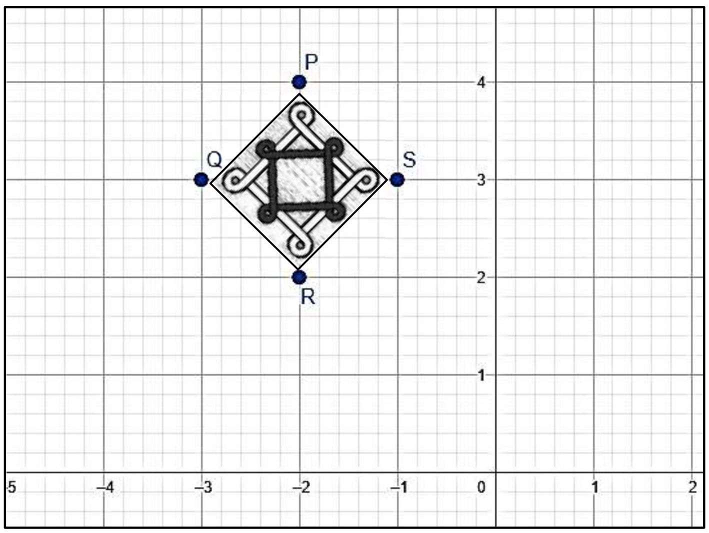


Each subsequent motif element is positioned three units to the right and four units upward from the previous one.

a. Determine the coordinates of the third peak point starting from the initial coordinate.

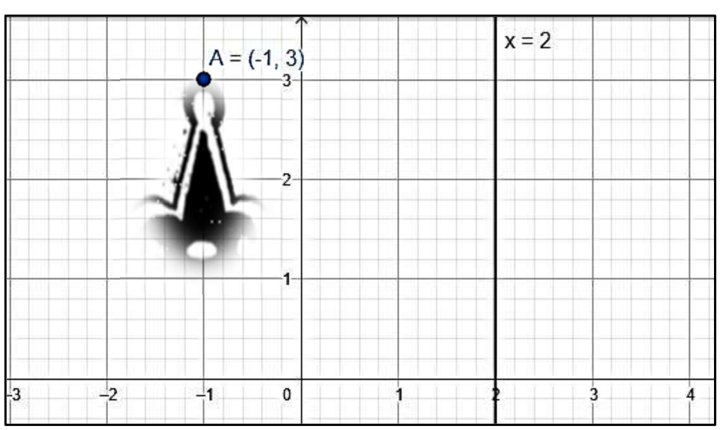
b. If the initial peak point X (1, 3) is translated three units to the left and four units downward, where will the third peak point be located from the new starting coordinate?
c. Suppose the artisan wants to create the motif on a single piece of fabric measuring 2 meters in length and 1 meter in width. How many motifs can the artisan produce at most, assuming one unit equals one decimeter?

2. Observe the following figure! Assume that a segment of carving art is taken from the Tapak Raja Sulaiman motif, as shown below.



The second motif is the result of a reflection over the y-axis
a. Determine the coordinates of points P′, Q′, R′, and S′ for the second motif.
b. Reflect the motif (from the original coordinate points) over the x-axis, and determine the coordinates of points P′, Q′, R′, and S′ for the second motif.
c. What are the coordinates of P″, Q″, R″, and S″ if the next motif is the result of a reflection over the y-axis followed by a reflection over the x-axis?

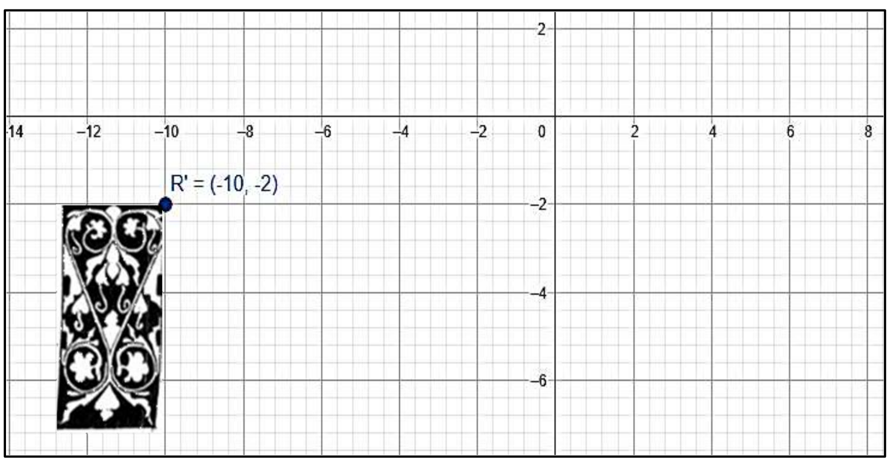
3. A batik artisan intends to design a uis fabric featuring the Teger Tudung motif, with one



of the motif's peak points located at point A, as shown in the figure below.

a. If the point is reflected across the line x = 2 to form the uis fabric pattern with the Teger Tudung motif, what is the image of point A (denoted as A′)?
b. If the image of point A is then reflected across the line x = –2 to create the following Teger Tudung motif pattern, what is the image of point A′ (denoted as A″)?
c. If the images A′ and A″ are then translated two units to the right and two units upward, and this translation is repeated three times, determine the resulting image of each point at every step. If a batik artisan uses the resulting images to determine the placement of the motifs on the fabric, illustrate the motif placement on the Cartesian coordinate plane.

4. A batik artisan plans to design a uis fabric pattern featuring the Puncak Tenggiang motif by rotating point R(x, y) about the origin O(0, 0) by 90° counterclockwise, as described below:



a. If the result of the rotation is R′(–10, –2), determine the original coordinates of point R in the first pattern that a batik artisan needs to create.
b. Determine the coordinates of the second and third motifs generated from the original point R in the first pattern through successive 90° counterclockwise rotations.
c. Determine the images of each point R, R′, R″, and R‴ from items (a) and (b) after being dilated concerning the origin O(0, 0) using a scale factor of 2. If a batik artisan uses these resulting images to decide the placement of the motifs on the fabric, illustrate the motif positions on the Cartesian coordinate plane.

Appendix

Student Response Sheet After Participating in Learning Activities Using The Project-Based Learning Model with The Ethnomathematics Approach Assisted By GeoGebra

Student Name: ______________________________
Class : ______________________________
School name : ______________________________

Objective

Purpose of using the questionnaire sheet: This is to collect response data from students after following the activity learning using a project-based learning model with an ethnomathematics-assisted GeoGebra in context system, kinship, bronze rakut sitelu at the wedding customs of the Karo people.

Instruction

Participants filled out the questionnaire as follows:

1) Provide a check mark (√) in the column that you consider appropriate to the existing assessment aspects, and
2) If necessary, provide constructive comments /suggestions.

Assessment aspect criteria:

Score 4 = Strongly Agree/Very Interesting /Very Happy /Very Understandable /Very Helpful /Very Training
Score 3 = Agree/ Interesting / Enjoyable / Understood / Helpful / Training
Score 2 = Less Agree / Less Interesting / Less Enjoyable / Less Understandable / Less Helpful / Less Training
Score 1 = Disagree/Not Interesting /Not Understandable /Not Helpful /Not Training

No.	Rated aspect	Rating Scale			
		1	2	3	4
1	**Interest in the Learning Process**				
	1. The study emphasizes this learning approach due to the selective use of GeoGebra software when required.				

No.	Rated aspect	Rating Scale			
		1	2	3	4
	2. This learning approach is appealing because it allows students to study the material in advance using GeoGebra software, before the teacher discusses it in class.				
	3. This learning approach attracts interest because it allows students to study in groups customized to their ability level in beginning mathematics, which increases their confidence.				
	4. This learning approach is appealing because it allows students to express their opinions when solving informal group problems.				
	5. This learning approach allows students to reflect independently and apply appreciation-based cultural practices, including Karo traditional cloth and carvings, to address informal problems effectively.				
2	**Motivation Towards Learning**				
	1. The present study focuses on activity-based learning that incorporates cultural context.				
	2. This learning approach is appealing because the teacher facilitates learning through an effective system application.				
	3. This learning approach encourages students to assist peers with difficulties understanding and solving informal problems.				
3	**Perceived Usefulness**				
	1. The project-based learning model, incorporating an ethnomathematics approach assisted by GeoGebra, helps students enhance their understanding of the material by connecting geometric concepts to everyday life.				
	2. Informal problems in the material transformation geometry are easy to imagine and solve.				
	3. The learning activities enable students to understand and appreciate their cultural values, making the material relevant to everyday life.				
	4. Through these learning activities, students engage in self-directed discussion groups, which foster the development of positive attitudes, empathy, and cooperation with peers.				

Notes:

Completing this questionnaire does not affect grades. Respond honestly, reflecting personal opinions. Write any comments or suggestions about the implemented learning activities in the space below.

____
____
____

Karo, ……………………………….
Respondents

(______________________________)

Appendix

Teacher Response Sheet After Participating in Learning Activities Using The Project-Based Learning Model with The Ethnomathematics Approach Assisted By GeoGebra

Teacher Name : ____
School name : ____

Objective
Purpose of using the questionnaire sheet: This is to collect teacher response data after following the activity learning using a project-based learning model with an ethnomathematics-assisted GeoGebra in context system, kinship, bronze rakut, sitelu, at the wedding customs of the Karo people.

Instruction
Participants filled out the questionnaire as follows:

1) Provide a check mark (√) in the column that you consider appropriate to the existing assessment aspects, and
2) If necessary, provide constructive comments /suggestions.

Assessment aspect criteria:

Score 4	=	Strongly Agree/Very Interesting /Very Happy /Very Understandable /Very Helpful /Very Training
Score 3	=	Agree/ Interesting / Enjoyable / Understood / Helpful / Training
Score 2	=	Less Agree / Less Interesting / Less Enjoyable / Less Understandable / Less Helpful / Less Training
Score 1	=	Disagree/Not Interesting /Not Understandable /Not Helpful /Not Training

No.	Rated aspect	Rating Scale			
		1	2	3	4
1.	**Interest in the Learning Process**				
	1. This learning approach engages students by having them use GeoGebra software only when necessary.				
	2. This learning approach is appealing because it allows students to study the material in advance through GeoGebra software, before the teacher discusses it in class.				
	3. This learning approach is appealing because students work in groups customized to their ability level in beginning mathematics, which enhances their confidence.				
	4. This learning approach is appealing because it allows students to express their opinions and collaboratively solve informal group problems.				
	5. This learning approach is appealing because it allows students to reflect independently and engage in appreciation-based cultural practices, such as using Karo traditional cloth (UIS) and carvings as a form of gratitude, effectively addressing informal problems.				
2	**Motivation Towards Learning**				
	1. This learning approach is appealing because it incorporates the cultural context of students.				
	2. This learning approach is appealing because it facilitates learning through the user-friendly GeoGebra software.				
	3. This learning approach encourages students to assist peers with difficulties understanding and solving informal problems.				
3	**Perceived Usefulness**				
	1. The project-based learning model, incorporating an ethnomathematics approach assisted by GeoGebra, helps students enhance their understanding of the material by connecting geometric concepts to daily life.				
	2. Informal problems in the material transformation geometry are easy for students to imagine and solve.				
	3. Student learning activities help students understand the values close to daily life.				
	4. Activity student learning follows practice student. Believe in active discussion groups and improve attitude, concern, and cooperation with colleagues and friends.				

Notes:
If there are any comments or suggestions regarding the implemented learning activities, please write them in the space provided below.

____   ____   ____

Karo, ……………………………….
Respondents

(______________________________)