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Developing Ethnomathematics-Based Geo-Puzzle Math Using the Pucuk Rebung Motif to Enhance Junior High School Students' Problem-Solving Skills

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Abstract
This study aimed to develop and evaluate Geo-Puzzle Math, an ethnomathematics-based manipulative learning medium incorporating the Acehnese Pucuk Rebung motif, to support eighth-grade students' mathematical problem-solving skills in geometry based on Polya's framework. Employing a Research and Development (R&D) approach using the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), the study involved expert validators, mathematics teachers, and 30 junior high school students in Langsa City, Aceh, Indonesia. Data were collected through expert validation sheets, teacher and student practicality questionnaires, and mathematical problem-solving pretests and posttests. Descriptive statistics and normalized gain (N-Gain) analysis were employed to evaluate product validity, practicality, and learning improvement. The results showed that Geo-Puzzle Math achieved an overall expert validation score of 90.25% (Very Valid) and a practicality score of 89.82% (Very Practical). Students demonstrated improvements across all four Polya problem-solving indicators, with N-Gain values ranging from 0.60 to 0.76 (Medium to High). The highest improvement occurred in understanding the problem (N-Gain = 0.76). These findings suggest that integrating culturally meaningful geometric patterns with hands-on manipulation may facilitate mathematical reasoning and contextual understanding while introducing local cultural heritage. Nevertheless, the limited sample and absence of reported controlled comparisons constrain causal interpretation. Further studies involving larger samples and comparative designs are recommended to establish the medium's effectiveness and generalizability.

Keywords: Ethnomathematics; Geo-Puzzle Math; Mathematical Problem-Solving; Polya's Framework; Pucuk Rebung; Geometry Learning.

INTRODUCTION

Learning media are tools or other materials that present information in a comprehensive manner and support the teaching and learning process (Pangastuti, 2019). Indonesian students' numeracy literacy skills remain low, according to results from the Programme for International Student Assessment (PISA) and the Computer-Based National Assessment (ANBK). One contributing factor is that the mathematics teaching materials currently in use are largely theoretical and fail to adequately link mathematical concepts to students' real-life contexts (Yunitasari et al., 2026). Problem-solving is a mathematical thinking process employed by students to find solutions to the problems they encounter (Mei et al., 2026). Previous research by Riska et al. (2026) supports this, noting an improvement in students' mathematical problem-solving abilities following the implementation of the Problem-Based Learning (PBL) model in mathematics instruction. So, the researchers were motivated to develop teaching materials in the form of e-modules that use technology and PBL methodology, which has been shown to enhance students' mathematical problem-solving skills. The use of educational games in junior high schools in Aceh Tamiang Regency remains limited; as a result, students' creativity and skills

in solving geometry problems have not fully developed. Therefore, implementing puzzle-based educational games in geometry instruction is necessary to boost students' creativity and problem-solving capabilities (Tupulu & Hartono, 2026). To address this challenge, this study develops an Android-based ethnomathematics puzzle game as an interactive learning medium that not only conveys subject matter but also highlights local cultural values. Numerous studies have reported on the effectiveness of the Jigsaw cooperative learning model in mathematics education; however, researchers have paid insufficient attention to integrating this model with digital learning media to enhance students' learning outcomes and critical thinking skills (Yendrita et al., 2026). Previous research indicates that integrating local wisdom into instruction can enhance students' environmental literacy, conceptual understanding, and skills (Imron et al., 2026).

The ability to recognize geometric shapes is an important aspect in the cognitive development of young children which needs to be developed through interesting and meaningful learning (Purnamasari et al., 2026). Puzzle media serves as a mathematics teaching aid for the topic of 2D shapes within geometry instruction. Consisting of image pieces, the puzzle facilitates student learning about 2D shapes through an assembly-style game (Nurwahyuningsih et al., 2024).

While there has been extensive research on ethnomathematics-based geometry learning media, most studies have focused predominantly on enhancing basic cognitive abilities such as problem-solving, mathematical literacy, and conceptual understanding (Irawan et al., 2024; Supriadi et al., 2021). Research specifically focused on developing interactive geometry learning media that integrates ethnomathematics to improve junior high students' problem-solving skills remains limited (Utami et al., 2023). Also, no prior research has integrated the rich ethnomathematical values found in the Pucuk Rebung motif as an authentic context for geometry learning within the development of manipulative or interactive learning media. So, there is a clear imperative to develop ethnomathematics-based geometry learning media featuring the Pucuk Rebung motif to serve as an effective, culturally responsive problem-solving tool for students. Also, no prior research has integrated the rich ethnomathematical values found in the Pucuk Rebung motif as an authentic context for geometry learning within the development of learning media (Yunitasari et al., 2026). So, there is a clear imperative to develop ethnomathematics-based geometry learning media featuring the Pucuk Rebung motif to serve as an effective, culturally responsive problem-solving tool for students.

Based on this premise, this study aims to develop ethnomathematics-based mathematics learning media featuring the Pucuk Rebung motif that is both practical and effective in enhancing the problem-solving skills of junior high school students. This development initiative is expected to foster innovation in the teaching of mathematical geometry strengthening conceptual understanding while simultaneously cultivating a positive attitude toward mathematics and increasing students' appreciation of local culture as an integral part of the national identity.

METHODS

Type of Research

This study on Geo-Puzzle Math employs a Research and Development (R&D) methodology. It focuses on an ethnomathematics-based learning medium incorporating the Pucuk Rebung to examine its validity, practicality, and effectiveness in enhancing the geometric problem-solving skills of junior high school students. The developed product integrates geometric concepts with mathematical elements found in the Pucuk Rebung motif, a traditional design characteristic of Langsa City and a part of Aceh's local cultural heritage.

The research consists of two primary phases. The first is product development, which encompasses needs analysis, design, prototype production, expert validation, and revision. The second involves product testing conducted through limited trials and field trials to determine the medium's practicality and its effectiveness in improving students' mathematical problem-solving abilities. To assess effectiveness, the study utilizes a quantitative approach with a one-

group pretest-posttest pre-experimental design. A single group of students completes a problem-solving test before engaging with the Geo-Puzzle Math medium, followed by an equivalent test after the learning activity. While this design can reveal changes in student ability following the use of the medium, the absence of a control group means it cannot be definitively concluded that these changes are solely attributable to the developed product.

Participants, Sample Size, and Selection Criteria

This study will be conducted at a junior high school in Aceh Tamiang, Aceh Province, with seventh-grade students serving as the primary participants. The seventh grade was selected because the geometric content addressed aligns with the current curriculum, and because students at this level require concrete learning media to grasp geometric concepts. The specific school and the implementation schedule will be determined once institutional permission is secured and the alignment between the content and the existing teaching schedule has been verified. Participants will be categorized into three groups: expert validators, participants for small-group trials, and participants for field trials. Mathematics teachers will serve as informants during the needs analysis phase and as respondents during the assessment of the product's practicality. Five expert validators are planned: two mathematics experts, two learning media experts, and one expert in culture or ethnomathematics. Validators will be purposively selected based on their educational background, competence, teaching or research experience, and understanding of the specific field they are to evaluate. Content experts will assess the accuracy of the mathematical concepts and the alignment of the problems with the learning objectives. Media experts will evaluate the quality of the design, readability, safety, durability, and ease of use. The cultural expert will assess the accuracy of the representation of the Pucuk Rebung motif and the relevance of the connection between this motif and the geometric concepts presented. Small group trial is planned, involving 10 seventh-grade students. Participants will be purposively selected to represent various levels of academic ability relatively high, medium, and low determined by their prior mathematics grades or existing preliminary test results, as confirmed by their teacher. The group must reflect the range of ability levels within the class, rather than consisting solely of high-achieving students.

Field trial is planned, involving approximately 30 students from a single seventh-grade class. The class will be selected based on the relevance of the learning materials, the school's readiness, and the approval of relevant authorities. Inclusion criteria require students to be actively enrolled in the class, participate in the instruction of the material under study, obtain necessary permissions or consents, and be willing to complete a pretest, the learning activities, and a posttest. Students who miss any of the primary assessments will be noted as having incomplete data; the handling of such data will be determined prior to the commencement of analysis. Whenever possible, all students in the selected class will be included to minimize selection bias. Different students will participate in the small group trial and the field trial to ensure that the experience gained from the initial trial does not unduly influence the results of the field trial. The final number of participants will depend on actual conditions at the school and will be reported transparently in the research report. Student participation will adhere to the ethics of educational research; the researchers will obtain permission from the school, explain the research objectives and procedures, and ensure the protection of the participants.

Research Subjects

The research subjects consisted of two groups: validation subjects and trial subjects. The validation subjects consisted of lecturers or experts with relevant disciplinary expertise: two mathematics content experts who assessed the alignment of the material with learning outcomes; two instructional media experts who evaluated the media's visual quality, design, and usability; and one expert in Acehnese culture or ethnomathematics who assessed the appropriateness of the local cultural elements integrated into the Geo Puzzle Math media. The trial subjects were 7th-grade junior high school students. A small group trial involved approximately 10 students representing high, medium, and low academic ability levels; this trial

aimed to assess the media's readability and usability, as well as to gather initial feedback on the developed product. Following revisions based on the small-group trial results, the product was tested with a larger group a single class of approximately 30 students. This stage involved measuring the media's effectiveness in enhancing students' mathematical problemsolving skills.

ADDIE Model Development Procedure

Analysis Phase

The analysis phase is the initial stage aimed at identifying needs for the development of learning media. This analysis was conducted through observation, interviews with mathematics teachers, and a review of documentation regarding the teaching and learning process at the school. The first analysis was a curriculum analysis. The researcher examined the Learning Outcomes (CP), Learning Objectives, and Learning Objective Flow for the Grade VII Junior High School (SMP) geometry curriculum. This analysis ensured that the media being developed aligned with the prevailing curriculum. The second analysis focused on student characteristics. This stage examined students' prior knowledge, learning styles, learning interests, and their level of understanding regarding geometry concepts. The analysis results indicated that most students still struggled to grasp abstract geometry concepts; therefore, concrete and engaging learning media were required. Subsequently, a teacher needs analysis was conducted. Interview results revealed that teachers required learning media capable of boosting student engagement, facilitating problem-based learning, and integrating local cultural elements to implement contextual learning. The next stage was a local culture analysis. The researcher identified mathematical values within the Pucuk Rebung motif, a distinctive Acehnese design. The analysis examined the geometric shapes, repeating patterns, symmetry, geometric transformations, angles, and 2D shape concepts inherent in the motif. The findings from this analysis served as the foundation for designing the Geo-Puzzle Math.

Design Phase

The design phase was carried out based on the results of the needs analysis. During this stage, the researcher created an initial design for the Geo-Puzzle Math media, integrating geometry concepts with the Pucuk Rebung motif. Activities included formulating learning objectives; establishing indicators for mathematical problem-solving skills based on Polya's steps; outlining the Geo Puzzle game flow developing Student Worksheets, creating assessment instruments; drafting pre-test and post-test questions; and preparing usage guidelines for both teachers and students. In addition, the visual design of the media was developed, encompassing puzzle piece shapes, media dimensions, color selection, typography, Pucuk Rebung motif illustrations, and the layout of each component to ensure the media was engaging, user-friendly, and suited to the characteristics of junior high school students.

Development Phase

The development phase involves realizing the previously formulated design. During this stage, a prototype of the Geo-Puzzle Math was created in accordance with the established design. Once developed, the media underwent validation by experts. This validation process aimed to assess the product's suitability regarding content, visual presentation, language, delivery, and the integration of ethnomathematical elements. Validators evaluated the product using a prepared validation form and provided suggestions and feedback regarding any shortcomings. All validator feedback served as the basis for product revisions, resulting in an improved version of the media.

Implementation

The implementation phase was carried out after the media was validated by experts. Implementation began with a pre-test administered to students to assess their initial mathematical problem-solving abilities. Subsequently, the teacher conducted lessons using the Pucuk Rebung motif ethnomathematics-based Geo-Puzzle Math, following the established lesson plan. Throughout the learning process, the researcher observed the activities of both the teacher and the students. At the end of the lesson, students took a post-test to measure improvements in

their mathematical problem-solving skills. Also, the teacher and students completed a questionnaire regarding the use of the developed media to evaluate its practicality.

Evaluation

The evaluation stage is conducted continuously throughout every phase of development. The purpose of evaluation is to assess the quality of the resulting product and determine necessary revisions. Formative evaluation takes place during the development process through expert validation, product revision, and small-group trials. Summative evaluation is conducted after implementation by analyzing student learning outcomes, teacher and student responses, and the feasibility of the instructional process. Evaluation results serve as the basis for refining Geo-Puzzle Math to ensure the final product meets the criteria of validity, practicality, and effectiveness.

Data Collection Techniques

Data for this study are collected using several techniques: observation, interviews, questionnaires, tests, and documentation. Observation is used to gather information regarding the mathematics learning process, teacher and student activities, and the implementation of the media during instruction. Interviews are conducted with mathematics teachers prior to the study to understand the learning environment, media requirements, and difficulties students face when learning geometry. Questionnaires are used to gather data on media validity from experts, media practicality based on teacher feedback, and student responses to the use of Geo-Puzzle Math. Tests are used to measure students' mathematical problem-solving abilities before and after using the learning media. These tests are administered as pre-tests and post-tests consisting of open-ended questions based on Polya's problem-solving indicators. Documentation involves collecting various supporting materials, such as instructional plans, activity photos, student work, and other research-related documents.

Research Instruments

The research instruments consist of expert validation sheets, observation sheets, interview guides, teacher and student response questionnaires, and mathematical problem-solving ability tests. The problem-solving ability test is designed based on the four indicators proposed by Polya: understanding the problem, devising a plan, carrying out the plan, and looking back (reviewing the solution). Before use, all research instruments undergo expert validation to ensure they meet content validity standards and are suitable for the study.

Data Analysis Techniques

The research data were analyzed using quantitative and qualitative descriptive analysis. Validity analysis is carried out on the validator assessment results using a percentage formula. Media is declared very valid if it obtains a minimum percentage of 81%. Practicality analysis was carried out based on the results of teacher and student response questionnaires. The percentage of practicality is calculated to determine the level of ease of using media during learning. Effectiveness analysis was carried out by comparing students' pretest and posttest results. Increased problem solving abilities are calculated using the Normalized Gain (N-Gain) formula. The N-Gain value is then interpreted into high, medium or low categories. Apart from using N-Gain, this research also carried out inferential statistical tests.

Indicators of Research Success

This research is declared successful if the Geo-Puzzle Math media based on ethnomathematics of the Pucuk Rebung motif meets three main criteria. First, media is declared valid if it obtains a minimum expert assessment percentage of 81% in the very valid category. Second, media is declared practical if it obtains a minimum percentage of teacher and student responses of 81% in the very practical category and can be used without experiencing significant obstacles in the learning process. Third, the media is declared effective if there is an increase in students' mathematical problem solving abilities as indicated by the N-Gain value being at least in the medium category (0.30) and there is a significant difference between the pretest and posttest

results at a significance level of 5%.

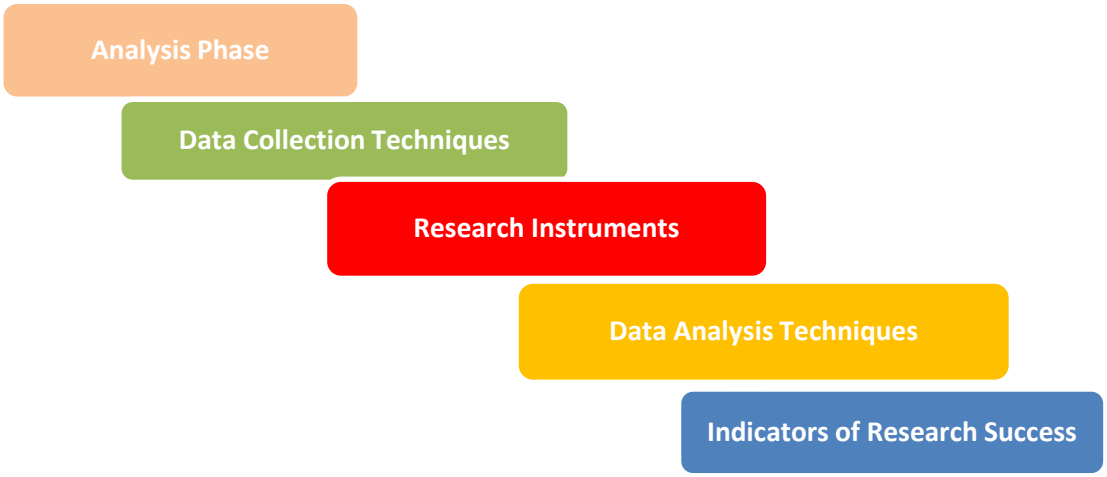


Figure 1. Model's of ADDIE

RESULT AND DISCUSSION

Result

This study aimed to develop an ethnomathematics-based learning medium, namely Geo-Puzzle Math incorporating the Pucuk Rebung motif, that is valid, practical, and effective in improving junior high school students' mathematical problem-solving skills. The development process employed the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. Each stage was carried out systematically to ensure that the resulting medium fulfilled the requirements of mathematical content and instructional design while also successfully incorporating elements of Acehnese local culture into mathematics learning.

The initial stage involved a needs analysis conducted through observations of mathematics instruction in Grade VIII junior high school classrooms, interviews with mathematics teachers, and the distribution of questionnaires to students. The classroom observations revealed that geometry instruction was still predominantly conducted through conventional approaches. Teachers generally presented mathematical concepts through lectures using textbooks and whiteboards as the main instructional resources. During lessons, students tended to act as passive recipients of information, primarily listening to explanations and taking notes, with limited opportunities to explore geometric concepts independently. This situation contributed to students' difficulties in understanding plane figures and the relationships among geometric shapes, particularly when they were required to solve problems involving reasoning and mathematical problem-solving. The teacher interviews further indicated that students' limited problem-solving abilities were influenced by several factors. According to the teachers, most students were able to solve routine exercises when the procedures closely resembled previously demonstrated examples. However, when confronted with contextual problems requiring deeper analysis, many students struggled to determine an appropriate solution strategy. The teachers also identified the limited availability of instructional media as another factor affecting the effectiveness of geometry learning. The media commonly used in the classroom consisted mainly of illustrations in textbooks or presentation slides, which provided insufficient opportunities for students to visualize geometric objects and their relationships in a concrete manner.

These findings were supported by the results of the student needs questionnaire. Most students reported that geometry was among the mathematics topics they found difficult to understand. Their difficulties were associated with the large number of formulas they were expected to memorize and the limited availability of learning resources that could help them develop a concrete understanding of geometric concepts. Students also indicated a preference for learning activities involving games, group work, and manipulatives rather than lessons

dominated by teacher explanations. Interestingly, nearly all students reported that they had never experienced mathematics instruction that explicitly connected mathematical concepts with local cultural contexts. Still, they were familiar with various traditional Acehnese motifs commonly found on woven fabrics, traditional house carvings, and architectural ornaments.

The results of the needs analysis served as the primary basis for designing the ethnomathematics-based Geo-Puzzle Math. The medium was developed to address students' need for learning resources that are engaging, interactive, and contextual while simultaneously introducing and strengthening awareness of local cultural values through mathematics education. The design stage began with the formulation of specifications for the learning medium. Geo-Puzzle Math was designed as a manipulative learning tool consisting of multiple plane-figure pieces with different shapes and dimensions. The pieces were designed to fit together and form the Pucuk Rebung pattern, a traditional Acehnese motif characterized by repeated and symmetrical triangular arrangements. This motif was selected because of its strong connection to geometry topics taught at the junior high school level, particularly triangles, similarity, congruence, symmetry, geometric transformations, area, and perimeter. In addition to the main puzzle medium, several supporting instructional components were developed. These included a teacher's guide, student activity sheets, problem-solving challenge cards, student activity observation sheets, student response questionnaires, teacher response questionnaires, and an assessment instrument for measuring mathematical problem-solving skills. All components were designed as an integrated learning package. Therefore, the learning activities were not limited to assembling the puzzle but were also structured to encourage students to engage in mathematical reasoning based on Polya's problem-solving framework: understanding the problem, devising a plan, carrying out the plan, and reviewing the solution.

Following the design phase, the initial prototype of Geo-Puzzle Math was developed and subjected to expert validation to assess its feasibility. The validation involved material experts, instructional media experts, and cultural experts. The summary of the expert validation results is presented in Table 1.

Table 1. Results of Geo-Puzzle Math Validity Assessment by Experts

Validation Aspect / Expert	Evaluated Indicators	Percentage	Category
Material / Content Expert	Alignment with Learning Outcomes (CP/TP), Accuracy of Geometric Concepts, Suitability with Polya's Problem-Solving Indicators	88.50%	Very Valid
Instructional Media Expert	Visual Appeal, Durability, Spatial-Manipulative Design, Ease of Use, Color Contrast & Layout	90.25%	Very Valid
Cultural / Ethnomathematics Expert	Authenticity of Pucuk Rebung Motif Representation, Cultural Value Integration, Appropriateness of Local Context	92.00%	Very Valid
Overall Average	Combined Expert Assessments	90.25%	Very Valid

As shown in Table 1, the developed Geo-Puzzle Math achieved an overall validity score of 90.25%, which falls into the "Very Valid" category. Specifically, the material expert assessment reached 88.50%, the instructional media expert reached 90.25%, and the cultural expert reached 92.00%. These results confirm that the media is theoretically feasible and aligns with learning outcomes, geometric concepts, and Acehnese ethnomathematical contexts before being implemented in the classroom.

Discussion

Once the design specifications had been established, the development of Geo-Puzzle Math was initiated by integrating geometric learning objectives with the cultural characteristics of the Acehnese Pucuk Rebung motif. The medium was constructed using durable materials to facilitate repeated use during mathematics lessons, while differently colored puzzle pieces were introduced to help students distinguish geometric shapes and identify their spatial relationships.

The incorporation of the Pucuk Rebung motif served both aesthetic and contextual purposes, connecting formal geometry with culturally recognizable visual representations. This design is consistent with previous arguments that culturally meaningful artifacts can provide relevant contexts for mathematical exploration (Sari et al., 2024). Moreover, Sahputra and Rahmi (2023) identified Pucok Reubong among the traditional ornamental motifs associated with Acehnese architecture, highlighting the cultural significance of such decorative elements. The integration of culturally meaningful patterns into instructional materials also corresponds with culturally responsive approaches that recognize students' everyday experiences and cultural knowledge as resources for mathematical learning (Acharya et al., 2021; Luecke, 2025). Nevertheless, cultural relevance alone does not ensure conceptual understanding; its instructional contribution depends on how cultural representations are translated into mathematically meaningful activities.

The initial product underwent expert validation involving mathematics content experts, instructional media experts, and Acehnese cultural experts. The mathematics content expert confirmed the alignment of the learning materials with the intended geometry objectives while recommending refinements to contextual problem statements and higher-order thinking activities, consistent with research emphasizing the importance of appropriately structured problem-solving tasks (Ayu et al., 2023). The instructional media expert recommended enlarging several pieces to improve usability during collaborative manipulation, whereas the cultural expert evaluated the appropriateness of the Pucuk Rebung representation. These recommendations informed revisions to the puzzle dimensions, color contrast, instructional organization, and cultural illustrations. Such iterative refinement reflects the importance of aligning learning objectives, representational accuracy, usability, and contextual relevance. Anwar and Umami (2025), for example, demonstrated the potential of systematically developed ethnomathematics-based learning materials to support numeracy and self-regulated learning. Similarly, Murti et al. (2026) highlighted the importance of evaluating teachers' needs and instructional feasibility when designing culturally relevant mathematics resources. Therefore, the validation process represents an important stage in establishing the content and design suitability of Geo-Puzzle Math, although expert judgments should be distinguished from direct empirical evidence of its effectiveness in improving students' achievement.

During classroom implementation, Grade VIII students were introduced to the relationship between geometric concepts and the Pucuk Rebung motif. The teacher explained how recognizable cultural patterns could be analyzed through plane figures, symmetry, and spatial arrangements before organizing students into small collaborative groups. Each group received Geo-Puzzle Math, student activity sheets, and problem-solving challenge cards. Initially, several students experienced difficulty determining the appropriate arrangement of puzzle pieces. Following a teacher demonstration, however, students increasingly explored alternative configurations, compared geometric properties, and discussed possible solutions. These activities are compatible with previous studies emphasizing the role of hands-on manipulation and spatial representations in mathematics learning (Gustina et al., 2025; Sukestiyarno et al., 2023). English (2025) similarly demonstrated that students can engage in sophisticated spatial reasoning when manipulating two-dimensional shapes under meaningful task constraints. The present classroom observations suggest that Geo-Puzzle Math provided opportunities for students to examine geometrical relationships through physical experimentation, although the extent to which these interactions independently improved spatial reasoning was not directly measured.

An important observation concerned the increasingly active classroom interactions during puzzle-based learning. Students compared possible arrangements, identified incorrect configurations, proposed alternatives, and justified the placement of geometric pieces. The teacher primarily acted as a facilitator, providing clarification and prompting further investigation when groups encountered difficulties. This interaction reflects an instructional transition from predominantly procedural explanation toward exploratory and collaborative

mathematical activity. Boonstra et al. (2026) emphasize that physical actions become educationally meaningful when teachers encourage students to recognize, articulate, and abstract the mathematical structures emerging from manipulation. Consequently, the potential contribution of Geo-Puzzle Math should not be attributed solely to physical interaction with the puzzle. Rather, mathematical understanding may be supported by the combination of material manipulation, guided questioning, collaborative explanation, and reflection. This interpretation also corresponds with international research indicating that teachers' understanding of culturally situated geometry influences the ways mathematical concepts are represented and discussed in classrooms (Sunzuma & Maharaj, 2022).

The practicality assessment provided positive evidence concerning the acceptability and usability of Geo-Puzzle Math. The overall mean practicality score reached 89.82%, placing the medium in the Very Practical category according to the study's assessment criteria. Teacher responses reached 93.50%, whereas student responses in the small-group and field trials reached 86.75% and 89.20%, respectively. The relatively high teacher evaluation suggests that the medium was perceived as manageable and appropriate for classroom instruction, while favorable student responses indicate its acceptability during learning activities. The difference between teacher and student ratings is also informative because it suggests that perceived instructional usefulness and learners' immediate experiences are not necessarily identical. However, these descriptive percentages primarily establish perceived practicality rather than learning effectiveness. The distinction is important because attractive and accessible instructional materials do not automatically produce measurable improvements in mathematical competence. Research on culturally responsive instructional design similarly emphasizes the need to distinguish the feasibility of educational resources from their demonstrated cognitive outcomes (Murti et al., 2026; Urwatul Wutsqa et al., 2026).

The mathematical relevance of Geo-Puzzle Math derives from the geometric structures represented through the Pucuk Rebung motif. Its repeated triangular configurations, symmetrical arrangements, proportional relationships, and patterned organization provide opportunities to investigate the properties of plane figures and geometric transformations. Through assembling and rearranging the puzzle pieces, students explored possible configurations involving rotation, translation, reflection, congruence, and spatial relationships. These activities transformed the motif from a decorative representation into a potential object of mathematical investigation. From an ethnomathematical perspective, the educational significance of cultural artifacts emerges when their underlying mathematical relationships are systematically interpreted and connected to formal concepts. Rosa and Orey (2011) conceptualized this process through ethnomodeling, emphasizing the relationship between culturally situated mathematical practices and formal mathematical representations. The present learning design illustrates this connection by using a familiar cultural form as a context for identifying mathematical properties and exploring possible solutions.

The potential value of physical visualization is supported by broader international evidence. Schönherr et al. (2024), in a meta-analysis involving 41 intervention studies and 10,562 participants, identified a moderate overall effect of external visualizations on mathematics learning (Hedges' g = 0.504). Notably, the analysis did not establish a general advantage of technology-based representations over analogous non-digital visualizations. This finding is relevant because Geo-Puzzle Math relies primarily on physical manipulation rather than digitally generated geometric models. Its potential effectiveness therefore depends on representational clarity, task quality, and opportunities for active mathematical interpretation rather than technological sophistication. Similarly, Boonstra et al. (2026) emphasize the relationship between bodily action and abstraction, while English (2025) illustrates how manipulative-based spatial modeling can encourage students to compare alternative arrangements and justify geometric decisions. Nevertheless, the present study did not directly compare physical manipulatives with digital representations; therefore, no claim of comparative superiority can be established.

The findings also align with Indonesian research investigating ethnomathematics-based learning and mathematical understanding. Hartoyo et al. (2025), in a meta-analysis of 15 quantitative studies involving 1,247 participants, reported a positive overall relationship between ethnomathematics-based instruction and mathematical achievement (d = 1.15), alongside a moderate effect on learning attitudes (d = 0.69). Prasetyawan and Masitoh (2025) likewise reported a substantial pooled effect on mathematical conceptual understanding, although their synthesis involved a smaller set of studies. More specifically, Istia et al. (2025) identified a positive combined effect of ethnomathematics-based geometry instruction among Indonesian junior high school students (d = 0.999), accompanied by considerable between-study heterogeneity. These findings support the educational relevance of cultural contexts in geometry instruction while also demonstrating that effects vary across research settings. However, the present study's practicality percentages and indicator-specific N-Gain cannot be directly compared with standardized effect sizes from these meta-analyses because they represent different statistical measures and research designs.

Further comparisons can be drawn with studies developing interactive ethnomathematics media for geometry instruction. Hidayatulloh et al. (2026) developed an Android-based ethnomathematics puzzle game for junior high school geometry and reported favorable validation, practicality, and learning outcomes. Hodiyanto et al. (2026) similarly developed an ethnomathematics-integrated Android application for secondary geometry learning and reported improvements in mathematical problem-solving performance, although their small pilot sample limited generalizability. These studies differ from Geo-Puzzle Math because they primarily employ digital learning environments, whereas the present medium integrates cultural patterns into a physically manipulable puzzle. Moreover, Kusumaningsih et al. (2026) examined mental rotation through ethnomathematics-based geometry assessment, emphasizing how culturally contextualized tasks can reveal students' spatial reasoning processes. The findings are conceptually complementary, but they do not establish that physical ethnomathematics puzzles are more effective than digital media. Rather, the studies collectively suggest that different instructional representations may provide distinct opportunities for geometric exploration, spatial reasoning, and problem-solving.

The application of Geo-Puzzle Math also offers an opportunity to examine mathematical problem-solving through Polya's four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. The reported indicator-level analysis showed that Understanding the Problem achieved the highest N-Gain of 0.76, categorized as High, while the remaining three indicators achieved gains within the Medium category. This pattern suggests that the learning activities were particularly associated with improvements in students' ability to interpret problem situations and identify relevant geometric information. The visual and manipulable characteristics of the puzzle may have made problem conditions more accessible by allowing students to observe and rearrange geometric components. However, the lower gain categories for planning, implementation, and evaluation indicate that recognizing a problem does not necessarily translate into equally strong performance throughout the complete problem-solving process. This interpretation corresponds with research identifying distinct cognitive challenges across Polya's stages (Sutisna & Pujiastuti, 2023). Accordingly, future instructional refinement should strengthen explicit strategy formulation, solution justification, and reflective checking rather than concentrating exclusively on problem interpretation.

From the perspective of spatial reasoning, puzzle assembly requires students to examine orientation, relative position, shape compatibility, and potential transformations. The process may therefore encourage mental rotation and visualization when students predict how individual pieces could fit into a larger geometric configuration. Sukestiyarno et al. (2023) highlighted the relevance of ethnomathematical learning trajectories for spatial abilities, while Kusumaningsih et al. (2026) demonstrated how culturally contextualized tasks can illuminate students' mental-rotation strategies. Similarly, the use of ethnomathematics-based media examined by Gustina et al. (2025) provides supporting evidence concerning spatial learning in

elementary geometry. Nevertheless, the present study should distinguish between opportunities for spatial reasoning and empirically established improvements in spatial ability. Although the observations documented students manipulating, rotating, and comparing puzzle pieces, spatial reasoning was not reported as a separately assessed outcome. Consequently, any proposed improvement in spatial competence should be treated as an interpretive possibility requiring direct measurement.

Beyond cognitive outcomes, Geo-Puzzle Math appeared to support students' interest in cultural representations and their willingness to participate in mathematics activities. Classroom observations suggested that students became more attentive when recognizing geometric characteristics within the Pucuk Rebung motif and increasingly engaged with the cultural context presented during instruction. These observations are compatible with the broader proposition that ethnomathematics can connect school mathematics with learners' sociocultural experiences. Acharya et al. (2021), in a Nepalese educational context, highlighted the importance of local knowledge and culturally relevant instruction, while Luecke (2025) proposed a culturally sustaining framework for mathematics curriculum development. Indonesian research also identifies positive relationships between ethnomathematics-based instruction and learning attitudes (Hartoyo et al., 2025). However, the present study did not report a dedicated, validated instrument for measuring cultural identity or cultural appreciation. Therefore, the observed enthusiasm and appreciation should be interpreted as contextual classroom observations rather than conclusive evidence of sustained affective transformation.

Theoretically, these findings extend the practical application of ethnomathematics and constructivist learning by illustrating how culturally embedded geometric representations can be organized into a manipulable instructional medium supporting systematic problem-solving. Pedagogically, the results suggest that teachers can combine cultural artifacts, collaborative puzzle activities, and Polya-oriented challenge cards to facilitate geometric exploration, explanation, and reflection. Particular attention should be given to the weaker problem-solving indicators through structured questioning, strategy comparison, and opportunities to evaluate completed solutions. Policy implications include the development of culturally responsive instructional resources, professional training in ethnomathematical task design, and support for affordable manipulatives that can be implemented without extensive digital infrastructure. These priorities are consistent with international and Indonesian perspectives on culturally situated mathematics education and instructional accessibility (Sunzuma & Maharaj, 2022; Hartoyo et al., 2025; Murti et al., 2026). Nevertheless, the adoption of Geo-Puzzle Math at a broader institutional level requires additional evidence concerning effectiveness, implementation costs, material durability, and applicability across different student populations.

The novelty of the present study lies in the pedagogical combination of the Acehnese Pucuk Rebung cultural motif, physically manipulable geometric puzzle pieces, and structured problem-solving activities based on Polya's framework within Grade VIII mathematics instruction. Unlike earlier studies primarily identifying mathematical concepts in cultural artifacts or developing technology-based ethnomathematical media, Geo-Puzzle Math operationalizes a specific Acehnese decorative motif as a reusable hands-on learning resource accompanied by collaborative challenge cards and indicator-oriented evaluation. Its contribution is therefore not the introduction of ethnomathematics or puzzle-based learning as entirely new concepts, but the contextualized instructional design that connects cultural representation, geometric manipulation, and mathematical problem-solving within a single learning sequence. This approach adds preliminary evidence concerning the practical implementation of physical ethnomathematics media while highlighting the importance of distinguishing product practicality, classroom engagement, and demonstrable mathematical effectiveness.

Several limitations should be acknowledged. First, the available findings emphasize expert validation, practicality assessments, classroom observations, and descriptive N-Gain results; they do not provide sufficient information in the supplied Discussion to establish the intervention's causal effectiveness relative to conventional instruction. Second, although the

overall practicality score was high, the number of participants, detailed scoring criteria, response distributions, and instrument reliability were not reported in the supplied text, limiting independent assessment of the findings. Third, the reported N-Gain values were incomplete for three of the four Polya indicators, restricting interpretation of differential improvement. Fourth, the intervention was situated within the Acehnese cultural context and Grade VIII geometry instruction, potentially limiting direct transferability to students from different cultural or educational backgrounds. Finally, students' spatial reasoning, cultural appreciation, and long-term retention were not assessed through separately reported validated instruments. Future research should employ larger and more diverse samples, controlled comparisons with conventional and digital media, complete indicator-level reporting, delayed posttests, and qualitative analyses of students' reasoning processes. Further investigations may also examine whether cultural familiarity, initial mathematical ability, teacher facilitation, and prior spatial experiences influence the effectiveness of Geo-Puzzle Math across different learning environments.

CONCLUSION

This study successfully developed an ethnomathematics-based learning medium, namely Geo-Puzzle Math incorporating the Acehnese Pucuk Rebung motif, following the five stages of the ADDIE development model (Analysis, Design, Development, Implementation, and Evaluation). The findings confirm that the developed media fulfilled the three primary criteria of educational product quality: it was declared very valid based on an overall expert validation average score of 90.25% (covering material, media, and cultural aspects); very practical as demonstrated by an overall average practicality score of 89.82% from teacher (93.50%) and student field trials (89.20%); and effective in enhancing students' mathematical problem-solving skills, supported by a significant increase in Polya's indicator performance with N-Gain scores ranging from 0.60 to 0.76 (Medium to High categories). Integrating local cultural motifs into a physical-spatial manipulative tool provided a concrete, engaging, and meaningful learning experience that bridged abstract geometric concepts with contextual real-world applications.

Practically, Geo-Puzzle Math serves as an innovative, student-centered instructional alternative for geometry teachers seeking to foster active learning, spatial visualization, and higher-order problem-solving skills in 21st-century classrooms. Culturally and theoretically, the implementation of this media demonstrates that ethnomathematics can effectively strengthen students' appreciation and preservation of local cultural heritage without compromising rigorous mathematical learning outcomes. Future research may explore the scalability of physical-spatial manipulative puzzles across broader geometry topics and investigate their long-term impact on affective dimensions such as mathematics anxiety and cultural identity.

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