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# Adventures of Geometry: An Ethnomathematics-Based Virtual Reality Learning Media in the Context of Benteng Pendem for Geometry Transformations

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**Abstract**

*This study aimed to develop Adventures of Geometry, an ethnomathematics-based Virtual Reality (VR) learning medium that integrates the architectural heritage of Benteng Pendem into the learning of geometry transformations. The study employed a Research and Development (R&D) approach using the ADDIE instructional design model, consisting of Analysis, Design, Development, Implementation, and Evaluation. Data were collected through expert validation sheets, student response questionnaires, classroom observations, and analysis of students' learning activities. The developed media achieved an average expert validation score of 89%, indicating a very valid category, and a practicality score of 88%, indicating a very practical category for classroom implementation. Analysis of students' learning activities showed that the immersive VR environment effectively facilitated students' understanding of translation and reflection, although additional instructional support remained necessary for rotation and dilation. The integration of immersive Virtual Reality with ethnomathematics through the cultural context of Benteng Pendem provides a meaningful learning environment that promotes conceptual understanding, spatial reasoning, and cultural awareness simultaneously. This study contributes to mathematics education by providing a systematically developed instructional framework for integrating Virtual Reality and ethnomathematics into culturally responsive geometry learning and offers an innovative alternative for teaching abstract geometry transformation concepts.*

**Keywords**: Ethnomathematics, Geometry Transformations, Learning Media Development, Virtual Reality

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## INTRODUCTION

Mathematics learning, particularly geometry transformations involving translation, reflection, rotation, and dilation, remains challenging for many students because these concepts require the ability to visualize and mentally manipulate objects in space. Unlike other geometry topics that primarily emphasize identifying shapes or calculating measurements, geometry transformations require students to understand how an object's position, orientation, or size changes while preserving its mathematical properties. Previous studies have reported that students frequently experience misconceptions and difficulties in understanding transformation concepts due to limited spatial visualization skills and the predominant use of static two-dimensional instructional representations. (Parong & Mayer, 2021; Makransky & Petersen, 2021). These findings indicate the need for learning media capable of dynamically visualizing transformation processes, thereby facilitating students' conceptual understanding of abstract mathematical concepts.

Among the technologies that can address these challenges, Virtual Reality (VR) is particularly promising because it provides immersive three-dimensional learning environments. Research shows that VR can significantly enhance students' engagement, spatial reasoning, and conceptual understanding in mathematics learning (Radianti et al., 2020; Bertrand et al., 2024; Hamilton et al., 2021). However, the educational value of VR extends beyond increasing learning motivation. VR is particularly well suited for teaching geometry transformations because it enables students to observe and manipulate geometric objects directly within virtual environments. Students can visualize how an object undergoes translation, reflection across a line, rotation about a fixed point, and dilation from multiple perspectives. Such dynamic and interactive visualization complements conventional instructional media by presenting object transformations more realistically, allowing students to gain more concrete learning experiences and gradually construct conceptual understanding.

In addition, the integration of cultural contexts into mathematics learning through ethnomathematics has gained increasing attention. Ethnomathematics connects mathematical concepts with cultural practices, enabling meaningful and contextual learning experiences. Studies have shown that ethnomathematics-based learning improves students' motivation, understanding, and cultural awareness (Rosa & Orey, 2021; D'Ambrosio, 2020; Zainovi et al., 2025). Cultural heritage sites, such as traditional architecture, contain embedded mathematical concepts that can be explored in geometry learning (Sholikhah et al., 2025).

Recent studies have attempted to integrate ethnomathematics with digital technologies. For instance, VR-based ethnomathematics learning environments have been shown to improve student engagement and provide contextual learning experiences (Hasanah et al., 2024; Setio, 2025). However, most studies focus on general geometry topics or emphasize learning outcomes rather than describing systematic development processes using instructional design models (Branch, 2020).

The critical synthesis of previous studies reveals three major research gaps. First, limited studies have specifically integrated Virtual Reality and ethnomathematics to support geometry transformation learning, despite the need for dynamic visualization in this topic (Hasanah et al., 2024; Setio, 2025). Second, although various cultural heritage sites have been explored from an ethnomathematical perspective, Benteng Pendem has received little attention as a context for VR-based mathematics learning (Sholikhah et al., 2025). Third, previous studies have primarily emphasized learning effectiveness, whereas fewer studies have focused on the systematic development and evaluation of instructional media in terms of validity and practicality (Radianti et al., 2020; Hamilton et al., 2021; Bertrand et al., 2024). These gaps justify the development of an ethnomathematics-based Virtual Reality learning medium for geometry transformations using the ADDIE instructional design model.

Therefore, this study aims to develop "Adventures of Geometry," an ethnomathematics-based Virtual Reality learning medium that utilizes the architectural features of Benteng Pendem as an authentic mathematical context to facilitate students' understanding of geometry transformations. The learning medium was systematically developed using the ADDIE instructional design model. The expected outcome of this study is a learning medium that meets the criteria of validity and practicality. Furthermore, this study contributes to mathematics education by providing a systematically developed instructional medium that integrates Virtual Reality, ethnomathematics, and the local cultural heritage of Benteng Pendem to support the learning of geometry transformations.

## METHOD

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation. The approach used in this study is predominantly inductive, as conclusions are drawn based on empirical data obtained from expert validation and field testing.

The research was conducted in a junior high school setting. The participants consisted of students in grade VIII who studied geometry transformation topics. The sampling technique used was purposive sampling, considering that the selected class had characteristics relevant to the research objectives. In addition, two experts were involved in the validation process, namely a media expert and a mathematics education expert.

The development process followed the ADDIE model as described below:

### Analysis

At this stage, a needs analysis was conducted to identify problems in learning geometry transformations. Data were obtained through classroom observations and informal interviews with teachers and students. The results indicated that students had difficulty understanding abstract transformation concepts and required more interactive and contextual learning media.

**Design**

In this stage, the structure of the learning media "Adventures of Geometry" was designed. The design included learning objectives, content organization, user interface, navigation flow, and integration of ethnomathematics elements from Benteng Pendem. The VR component was also planned to visualize transformation concepts interactively.

**Development**

The media was developed using several digital platforms, including MIT App Inventor, Canva, and VR-based applications. The developed product was then validated by experts using validation instruments to assess content accuracy, media design, usability, and cultural relevance.

**Implementation**

The validated media was implemented in a limited trial involving students. During this stage, students used the media in learning activities, including exploring VR environments and completing tasks related to geometry transformations.

**Evaluation**

Evaluation was conducted to determine the validity and practicality of the media. Revisions were made based on expert feedback and student responses to improve the quality of the product.

Data were collected using several instruments:
(1) Expert validation sheets to assess the validity of the media,
(2) Student response questionnaires to measure practicality and engagement,
(3) Observation sheets to record student activities during learning, and
(4) Documentation of students' work as evidence of learning outcomes.

The data were analyzed using descriptive quantitative and qualitative techniques. Quantitative data from validation sheets and questionnaires were converted into percentage scores and categorized into levels such as very valid, valid, practical, and less practical. Qualitative data from observations and expert suggestions were analyzed descriptively to support the interpretation of the results.

Students' work was analyzed to identify their understanding of geometry transformation concepts. The analysis focused on students' ability to apply translation, reflection, rotation, and dilation in contextual problems related to Benteng Pendem. Errors and misconceptions were identified and used as a basis for evaluating the effectiveness of the developed media.

Assessment in this study consisted of both formal and informal evaluation. Formal assessment was conducted through structured tasks and quizzes embedded in the learning media. Informal assessment was carried out through observations of student interactions, participation, and responses during the learning process. These assessments provided comprehensive information about students' cognitive and affective learning outcomes.

Overall, this method ensured a systematic development process and comprehensive evaluation of the learning media, resulting in a valid and practical product for supporting geometry transformation learning.

## RESULT AND DISCUSSION

### Result

The results of this study present the validity and practicality of the developed learning media "Adventures of Geometry," supported by expert validation, student responses, and evidence from students' work.

The validation process involved a media expert and a mathematics education expert. The assessment covered four aspects: content feasibility, media design, usability, and cultural relevance. The results are shown in Table 1.

Table 1. Expert Validation Results

| Aspect Score | (%) | Category |
|---|---|---|
| Content Feasibility | 88% | Very Valid |
| Media Design | 90% | Very Valid |
| Usability | 86% | Very Valid |
| Cultural Relevance | 92% | Very Valid |
| **Average** | 89% | Very Valid |

Table 1 shows that the average validation score reached 89%, which falls into the "very valid" category. This indicates that the developed media is appropriate in terms of content accuracy, design quality, usability, and integration of ethnomathematical elements. The high score in cultural relevance confirms that the use of Benteng Pendem successfully represents ethnomathematical aspects within the learning media.

Product Visualization

The developed media "Adventures of Geometry" is presented through several key interfaces as shown in the following figures.

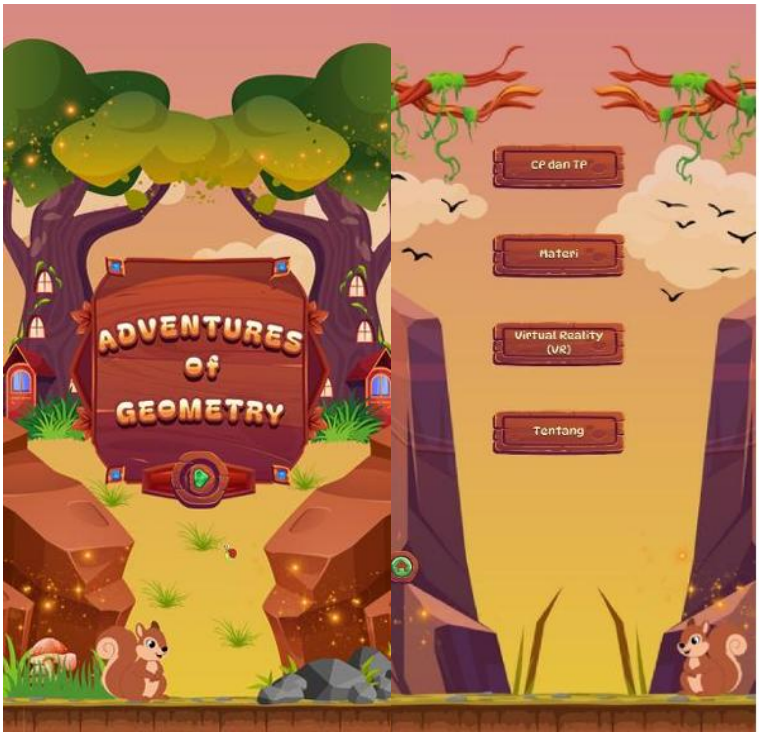


Figure 1. Main Interface of "Adventures of Geometry"

The main interface provides structured navigation, including menus for materials, VR exploration, and evaluation. This design supports students in accessing learning content systematically.

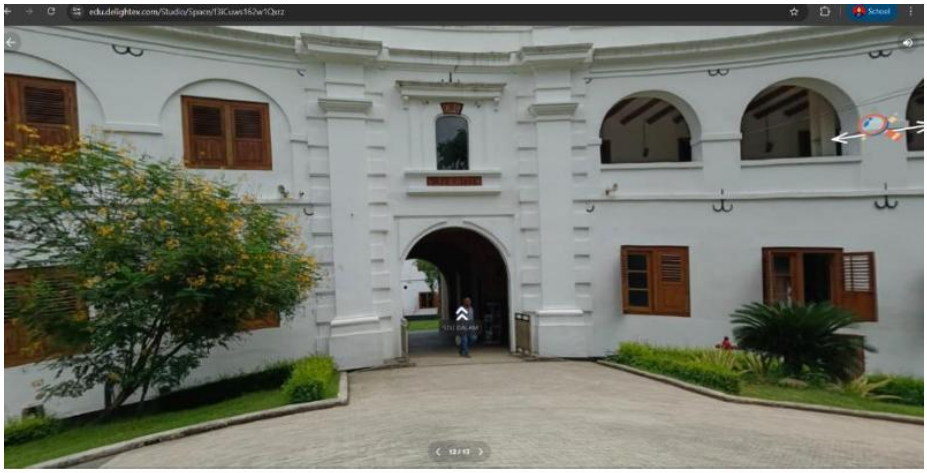

Figure 2. Ethnomathematics Context of Benteng Pendem in VR Environment

Figure 2 illustrates how the Benteng Pendem structure is visualized in a VR environment. The geometric elements embedded in the building are used as contextual representations of mathematical concepts.


Figure 3. Visualization of Geometry Transformations in VR

The VR feature enables students to observe transformations such as translation, reflection, rotation, and dilation interactively, allowing them to manipulate objects directly.

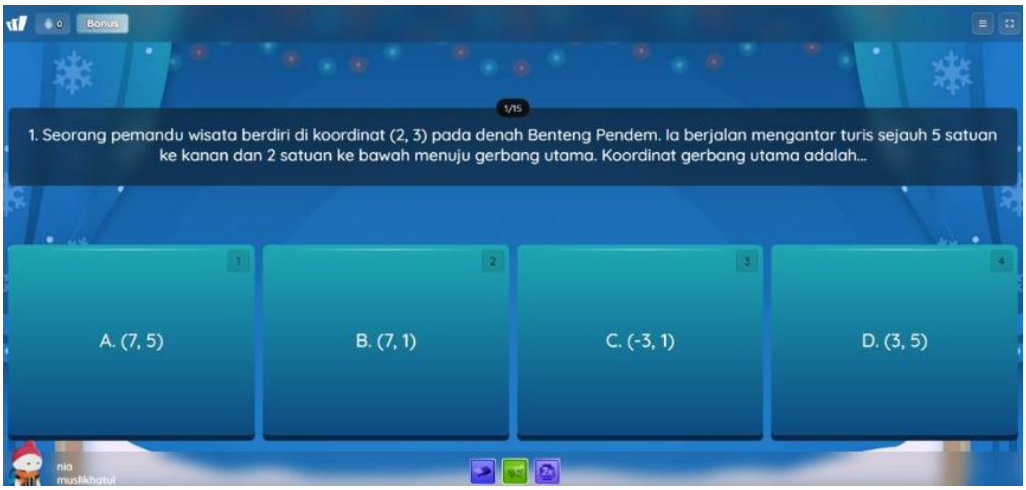


Figure 4. Student Interaction and Quiz Interface

This interface presents students' interactions with learning activities and the embedded quizzes provided in the media. The quizzes are integrated as part of the learning evaluation following the VR exploration.

The practicality of the media was evaluated through student response questionnaires. The results are presented in Table 2.

Table 2. Student Response Results

| Indicator | (%) | Category |
|---|---|---|
| Ease of Use | 87% | Practical |
| Attractiveness | 91% | Very Practical |
| Learning Engagement | 89% | Very Practical |
| Understanding | 85% | Practical |
| **Average** | 88% | Very Practical |

Table 2 indicates that the media achieved an average score of 88%, categorized as "very practical." Students reported that the media was easy to use, visually engaging, and helpful in understanding abstract concepts.

The analysis of students' written work showed that most students were able to correctly solve translation and reflection problems after using the developed media. In the translation tasks, students accurately determined the direction and distance of object displacement on the Cartesian plane, while in the reflection tasks they correctly identified the reflected images across the specified axes. In contrast, several students experienced difficulties with rotation and dilation, particularly in identifying the center of rotation, determining the direction of rotation, and calculating the scale factor in dilation.

Overall, the results show that the developed learning media met the validity and practicality criteria. Furthermore, the analysis of students' work revealed that students performed better on translation and reflection tasks than on rotation and dilation tasks.

**Discussion**

The findings of this study indicate that the developed learning media is both valid and practical. These results support previous studies that highlight the effectiveness of Virtual Reality in enhancing students' engagement and spatial understanding (Radianti et al., 2020; Makransky & Petersen, 2021; Bertrand et al., 2024). However, in this study, the effectiveness of VR is not only attributed to its immersive characteristics, but also to the structured learning design within the Adventures of Geometry media. Through interactive visualization, students were able to observe geometric transformations more concretely, such as changes in position in translation, symmetry in reflection, orientation changes in rotation, and scale changes in dilation.

This result is also consistent with constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction and experience (Parong & Mayer, 2021). In the developed media, students constructed their understanding by exploring the VR environment, observing geometric representations, and completing interactive quizzes. The visualization of geometric transformations allowed students to interpret changes in position, orientation, and size through visual exploration. Immediate visual feedback from the quiz results helped students check their answers and understand their level of understanding, supporting active learning through observation and interpretation rather than passive learning. (Cunha et al., 2025)

Furthermore, the integration of ethnomathematics through the Benteng Pendem context strengthens the meaningfulness of learning. This finding aligns with the work of Rosa and Orey (2021) and D'Ambrosio (2020), who argue that mathematics learning becomes more effective when it is connected to students' cultural backgrounds. Similarly, recent studies confirm that ethnomathematics-based learning enhances students' motivation and conceptual understanding (Zainovi et al., 2025).

In this study, the ethnomathematics integration was operationalized through specific architectural elements of Benteng Pendem. The main gate and entrance structures were used as references in translation activities, while doors and windows were utilized to represent reflection through their spatial symmetry. The arrangement of rooms, including smaller interior spaces and logistical or barrack areas, was used to illustrate spatial relationships in geometry learning. These architectural components were systematically embedded into the VR environment, allowing students to relate geometric transformation concepts directly to real cultural structures.

The analysis of students' work showed that VR supported students' understanding of basic transformations, particularly translation and reflection. Students were generally able to determine object displacement and identify symmetrical images correctly. However, difficulties were still found in rotation and dilation tasks. These difficulties may be caused by the complexity of determining rotation centers, interpreting rotation direction and angle, and understanding scale factors in dilation simultaneously. This indicates that although VR provides strong visual support, certain abstract mathematical procedures still require additional scaffolding. Therefore, instructional support such as step-by-step guidance, teacher facilitation, and structured prompts is still necessary to strengthen students' conceptual understanding. (Hasanah et al., 2024).

Overall, the findings indicate that integrating ethnomathematics and VR through a systematic development model (ADDIE) can produce valid and practical learning media for geometry learning. It also contributes to the development of research on technology-enhanced ethnomathematics in mathematics education.

## CONCLUSIONS

This study develops "Adventures of Geometry," an ethnomathematics-based Virtual Reality learning media for geometry transformation learning. The results of the study indicate that the developed media is feasible to be used in learning, as it meets the criteria of validity and practicality based on expert validation and student responses.

Specifically, the validity results show that the media is appropriate in terms of content, design, usability, and cultural integration. Meanwhile, the practicality results indicate that the media is easy to use, engaging, and supports students in understanding basic concepts of geometric transformations. In this study, students were able to better understand translation and reflection, although difficulties were still found in rotation and dilation concepts.

The analysis of students' work suggests that additional instructional support is needed, particularly in the form of scaffolding, guided instruction, and repeated visualization to help students understand more complex transformation concepts. This indicates that the use of technology needs to be complemented with appropriate pedagogical strategies.

The main contribution of this study lies in the development of VR-based learning media that integrates the local cultural context of Benteng Pendem using the ADDIE development model. This integration provides a structured way to connect cultural heritage with mathematical concepts in geometry transformation learning.

This study is limited by the small number of participants, the limited scope of implementation, and the absence of effectiveness testing using experimental design such as pre-test and post-test comparison. Therefore, future research is recommended to conduct large-scale experimental studies, measure learning effectiveness more rigorously, and explore long-term learning outcomes as well as adaptive or guided features in VR-based mathematics learning.

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