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Development of Geoarcala Roblox Game Integrating Ethnomathematics of Magelang Temples to Enhance Critical Thinking Ability

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Abstract

The ability to think critically is a vital skill in mathematics education. However, abstract and insufficiently contextualized instruction, especially in circular solid such as cylinders, hinders its optimal development. Integrating local cultural contexts through an ethnomathematics approach into game-based learning media offers a potential solution. This research intends to generate a learning game integrated within Roblox, namely Geoarcala, that integrates the ethnomathematics of temples in Magelang, and to evaluate its validity, practicality, and effectiveness in enhancing students' critical thinking ability. A Research and Development (R&D) design incorporating the ADDIE framework was utilized. The participants included 23 ninth-grade students from class IX A at SMP Negeri 1 Salaman. Data collection methods comprised interviews, questionnaires, and tests. The validation results indicated that the media was valid (85.16% by content experts and 80.42% by media experts). The practicality test showed very practical results based on student (83.85%) and teacher (85%) responses. A paired-samples t-test revealed significant media effectiveness ($t=10.68$ and $df = 22$, $p = 0.001$, Cohen's $d = 2.227$). The average N-Gain score of 0.30 shows a moderate degree of improvement. These result indicate that the Geoarcala game is valid, highly practical, and shows moderate potential for enhancing students' critical thinking ability.

Keywords: Geoarcala; Roblox; Ethnomathematics; Magelang temples; Critical thinking

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INTRODUCTION

In the twenty-first century, education must concentrate on mastering material (Consoli et al., 2024; Major et al., 2021; Palinussa et al., 2025) as well as on fostering the 4C competencies, particularly critical thinking skills (Widiyono & Ghufron, 2024; Ye & Xu, 2023), in order to advance science and information and communication technology. In order for students to adjust to ever-changing real-world challenges, they must be able to analyze information, assess solutions, and make rational judgments (Asriyanti & Andrijati, 2024; Kocak et al., 2021; Lancrin, 2023; Rivas et al., 2023). In the context of mathematics learning, critical thinking ability play a very strategic role (Hattori et al., 2025; Kacerja & Julie, 2023; Monteleone et al., 2023), especially in the geometry of solid shapes (Wu et al., 2024). Learning this material does not simply require memorizing formulas, but rather the ability to visualize spatial forms concretely and relate them to contextual problems (Herheim, 2023; Su et al., 2022). However, the current mathematics learning process generally still focuses on routine, procedural problems (Dias-Oliveira et al., 2024; Xu et al., 2023), so students' critical thinking ability are generally still in the low to moderate category (Aston, 2023; Putri et al., 2023).

The influence of overly abstract and procedural methods of learning is sharply experienced by students when they encounter the subject of solids with curved sides, especially

cylinders. This area of study requires advanced spatial skills, yet it is frequently presented in a traditional manner utilizing textbooks (Florio, 2022; Su et al., 2022), which complicates the students' ability to envision models and their practical usage in everyday situations (Adha, 2024; Chivai & Soares, 2022). This observed scenario corresponds with findings from observations and discussions with a ninth-grade math instructor at the State Junior High School of 1 Salaman. Learners at this institution have been noted for facing considerable challenges in translating real-life scenarios into mathematical representations related to cylinders. This challenge is intensified by the limited educational resources currently utilized, which consist mainly of passive access via Google and YouTube searches. Nonetheless, findings from a student needs assessment conducted in the area reveal that approximately 93% of pupils expressed a strong desire for educational tools that could foster their critical thinking skills through targeted challenges or tasks. Due to the insufficient support for the requirement of mission-centric interactive resources, the critical thinking ability of students in this class remain considerably low (Jumariati, et al., 2024), which is substantiated by an average pretest score of 28.91.

Responding to these problems, a contextual learning approach is needed that can transform abstract geometric concepts into concrete forms that are easily recognized by students (Umbara et al., 2023; Wangsa et al., 2024). The approach considered most relevant to bridge this gap is ethnomathematics (Johnson et al., 2022; Rodríguez-Nieto et al., 2025). The selection of the State Junior High School of 1 Salaman as the research location provides a very strategic geographical advantage, considering that this school is located in the Magelang area which is rich in cultural heritage, such as Borobudur Temple, Mendut Temple, Pawon Temple, and Ngawen Temple. The architecture of these temples physically contains real representations of circular solids, especially cylindrical and hemispherical structures. Through this integration of local ethnomathematics, the temple is not only seen as a historical object, but is optimized as a cognitive bridge for students to see the geometric form of cylinders concretely in their surroundings.

Previous research has examined numerous approaches to overcome students' difficulties in learning abstract mathematics that is far from real life. Specifically, previous research related to critical thinking ability in geometry shows that according to Andang et al. (2026) students often face obstacles in visualizing the concept of geometric shapes, and according to Putra & Akbar (2025) students tend to only memorize formulas without analyzing them in depth. Furthermore, the integration of local culture through ethnomathematics has been shown to bridge the abstractness of these concepts by presenting a more meaningful context (Musawwir et al., 2021; Purniati et al., 2022). Despite the significant promise that ethnomathematics holds, its application in enhancing critical thinking skills has primarily relied on static or two-dimensional resources. This is evident in the study conducted by Agustina, et al. (2024), who created Student Worksheets (LKPD) that incorporate cultural aspects, and in the research by Supriyadi, et al. (2024), who developed e-modules based on ethnomathematics. The use of two-dimensional media has fundamental limitations because it does not facilitate comprehensive spatial visual exploration (Ka et al., 2025).

On the other hand, interactive 3D digital platforms such as Roblox have been shown to significantly increase student engagement (Faridah & Deng, 2024; Hamadneh et al., 2025; Hsu & Wu, 2023; Hui & Mahmud, 2023; Morreale & Rosa, 2024; Yolal, 2022), but their use in education still focuses on nonspatial topics, such as natural disaster mitigation simulations (Maulida et al., 2023) and financial literacy (Vieira et al., 2025). There is a recent innovation that uses a Roblox-based Virtual Reality environment to explore historical buildings (Yumna et al., 2025), but this research is limited to improving basic numeracy literacy and does not address the integration of problem solving with critical thinking indicators specific to geometry. Therefore, there is still a gap in the fact that there has been no research that combines the discovery of ethnomathematics objects spatially in a 3D virtual environment with the

provision of stimulating questions that train and direct students in solving problems based on indicators of critical thinking ability.

To address this gap, this study developed Geoarcala, a Roblox-based mathematics learning tool that explores the ethnomathematics of temples in Magelang. The novelty of this research lies in the visual exploration process, which integrates ethnomathematics with the provision of stimulating questions that foster critical thinking ability. Geoarcala presents temple architecture as a 3D virtual environment that can be explored. Students are not only presented with direct questions, but also challenged to explore the temple and independently identify which parts of the building resemble a cylinder. When students interact by clicking on the appropriate object, the system displays an interface containing initial trigger questions that serve to train and stimulate students' thinking patterns. After the stimulation phase, students are guided to address problems that are organized according to critical thinking ability indicators. This mechanism is designed to bridge students' difficulties in identifying mathematical concepts in real cultural heritage while simultaneously triggering analytical reasoning integrated into the game scenario.

This research establishes clear limits from the beginning to prevent making too broad claims. It specifically examines the subject of curved-sided shapes, particularly cylinders, focusing on developmental interventions that are tested in just one experimental class at State Junior High School 1 Salaman. Specifically, the goals of this research are to (1) create and produce a valid Roblox Geoarcala game media that integrates ethnomathematics related to temples in Magelang, (2) produce Geoarcala media that is user-friendly for learning purposes, and (3) assess the initial effectiveness of Geoarcala media in helping to enhance students' critical thinking skills.

METHOD

Research Design and Procedures

The research approach utilized in this study is Research and Development (R&D) focused on creating a learning media in the form of the Geoarcala game that incorporates ethnomathematics. Additionally, it seeks to assess the validity, practicality, and the initial effectiveness of the product that has been developed. This development research adopts the ADDIE model, which includes the phases of Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The reason for selecting the ADDIE model is its organized and methodical phases, which are well-suited for crafting educational media. An illustration of the stages within the ADDIE development model can be found in Figure 1 below.

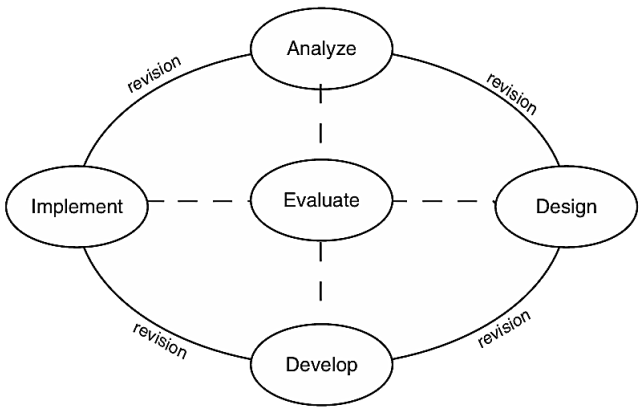

Figure 1. Stages of the ADDIE development model

During the analysis phase, several activities were conducted, including an analysis of learning media needs through questionnaires. Next, curriculum analysis, student characteristics analysis, and available resources analysis were conducted through teacher interviews. The learning materials were created using the questionnaire and interview results as a starting point for analysis.

The next phase was the design phase. Establishing development goals and learning outcomes, product design, and storyboarding were all part of the design phase. The media's content was chosen based on the development goals and learning objectives that were established. The product was designed by collecting the data required for media development. Moreover, storyboarding acted as a preliminary roadmap to aid in the creation of the learning medium's look and flow.

The development stage consists of several steps, including: a) developing the required media and instrument designs based on the previous stage, which are then validated by experts; b) evaluating the learning media by experts competent in media and materials and able to provide input to improve the developed media; c) conducting small group trials to determine the practicality of limited media use; and d) revising the validated media based on input from media and materials experts and the results of the small group trials.

Material and media experts have certified the media that has been created and determined to be suitable for testing research subjects during the implementation phase. Pre-tests and post-tests are performed at this point to gauge the media's initial success in fostering the development of critical thinking ability. Following the trials, students and teachers complete questionnaires to gauge the usability of the media employed.

Next, the evaluation phase is carried out by comparing the pre-test and post-test results to determine the media's initial efficacy. Furthermore, feedback from instructors and students is examined to provide a basis for further product improvements.

Participants

In this research, the investigator worked with a group of 216 students from the ninth grade at the State Junior High School of 1 Salaman. The method employed for sampling was purposive sampling. This approach to sampling is conducted with a particular intention to choose individuals from the population for inclusion in the study (Palinkas et al., 2015). For this research, 23 students from Class IX A at the State Junior High School of 1 Salaman were selected as samples since their pre-test scores for critical thinking skills were still quite low, indicating a need for improvement.

Instruments

The tools used for this research included both test and non-test items. The test items were made up of questions given before and after the study, while the non-test items included surveys, question guides for interviews, and observation forms. The surveys featured were a questionnaire about media needs, a validation questionnaire, and a practicality questionnaire. The media needs questionnaire included questions about the math learning process and what kind of learning tools are needed. Its purpose was to find out how much students need learning tools using the Roblox game.

The validation questionnaires involved three types: one for materials, one for media, and one for test instruments. The material expert validation questionnaire was used to evaluate the learning components and content, as well as the language used. The media expert validation questionnaire examined elements like media design, visual communication, and how ethnomathematics is combined. The validation questionnaire for the critical thinking ability test was used to evaluate the material, structure, and language used.

The practicality questionnaire had two parts: one for students and one for teachers. This was designed to find out how practical the media is for both groups. The practicality questionnaire looked at how easy it is to use, efficiency in time and effort, support for learning, and how appealing and comfortable the media is to use.

The interview guide was aimed at mathematics teachers to obtain information regarding learning difficulties in curved-sided solid geometry, students' critical thinking ability, and the application of learning media. Interviews were also used to analyze the school curriculum and resources, including supporting facilities, internet connection, and digital device usage policies.

Furthermore, the interviews were aimed at exploring the potential use of the Roblox game and the integration of an ethnomathematics approach in mathematics learning. This study was supplemented by an observation sheet for learning implementation to determine the implementation and dynamics of media use during the study.

The tests used in this study were descriptive pre-tests and post-tests, each containing two questions aimed at measuring students' critical thinking ability. Each question item consisted of sub-questions, each measuring indicators of critical thinking ability, outlined through questions a-f. Question (a) interpretation: measures the ability to identify important information in the problem. Question (b) analysis: measures the ability to explain relationships between information to understand the problem. Question (c) explanation: measures the ability to determine and write appropriate formulas along with the reasons for their use. Question (d) inference: measures the ability to perform calculations to solve problems and draw conclusions based on those calculations. Question (e) about evaluation: gauges how well students confirm the accuracy of their steps and results with logical reasoning related to the issue. Question (f) self-regulation: measures the ability to recheck calculation results through re-substitution or using different solution methods. Below is the grading rubric that was used for the study.

Table 1. Critical thinking ability test instrument assessment rubric

Indicator	Assessment Criteria	Score
Interpretation	– Students can recognize all important information completely, accurately, and relevantly to the problem.	3
	– Students can recognize important information, but some information is incomplete.	2
	– Students do not identify important information or some information is incorrect.	1
	– Students do not write down an answer.	0
Analysis	– Students can describe the relationships between data/information logically, systematically, and accurately, thus aiding understanding of the problem.	4
	– Students can describe the relationships between data clearly, but not in sufficient depth.	3
	– Students can describe the relationships between data, but inaccurately or unclearly.	2
	– Students are unable to connect data or provide incorrect explanations.	1
	– Students do not write down an answer.	0
Explanation	– Students write the correct formula/strategy and provide a logical and contextually appropriate rationale for its use.	3
	– Students write the formula correctly, but the rationale is inaccurate or not explained.	2
	– Students write the formula or strategy incorrectly and do not provide a rationale.	1
	– Students do not write down an answer.	0
Inference	– Students computed the values accurately, using complete steps, and writing correct conclusions.	4
	– Students computed the values accurately, using inaccurate steps, and writing correct conclusions.	3
	– Students computed the values and draw conclusions, but some errors occurred.	2
	– Students made incorrect calculations and drew conclusions that were inappropriate or incomplete.	1
	– Students do not write down an answer.	0
Evaluation	– Students are able to logically assess the accuracy of results and provide strong reasons appropriate to the context of the problem.	3

Indicator	Assessment Criteria	Score
	– Students are able to logically assess the accuracy of results, but the reasons provided are not very accurate.	2
	– Students are able to assess results, but there are errors in the assessment or the reasons are not accurate.	1
	– Students do not write down an answer.	0
Self-Regulation	– Students do double-check the answer accurately and completely.	3
	– Students do double-check the answer, but the calculation was incomplete.	2
	– Students do double-check the answer, but the calculation was incorrect.	1
	– Students show no effort to double-check the answer.	0

Considering that the test instrument is descriptive, objectivity and consistency of assessment are key concerns that must be controlled. The test results were assessed by a single researcher. To minimize subjectivity and maintain consistency, the researcher used the assessment rubric guidelines in Table 1 as the absolute standard. Furthermore, the assessment procedure was conducted horizontally per sub-question. This approach ensured that each answer sheet was scored consistently.

Two mathematics instructors and one professional lecturer initially tested the test instrument's content validity to make sure the content was appropriate for the measured ability indicators before it was utilized in the implementation step. Based on the results of the expert assessment calculated using Aiken's V content validity formula (Aiken, 1985), the content validity value obtained was 0.86 for the pre-test and 0.82 for the post-test. The test instrument is declared feasible if it has a content validity value in the high category, namely with a V value > 0.80 (Retnawati, 2016). Thus, the pre-test and post-test instruments are declared valid in terms of content and suitable for use.

Next, the test instrument was piloted on 31 ninth-grade students outside the research sample to measure construct validity, instrument reliability, discriminatory power, and difficulty level. Construct validity was calculated using the Pearson Product-Moment correlation. Based on the results, of the three test item designs, two items were declared valid on each instrument. Items 1 and 2 were for the pre-test, and items 2 and 3 were for the post-test.

The instrument's reliability was tested using the Cronbach's alpha coefficient to determine the instrument's level of internal consistency in measuring the same ability at different times and under different conditions (S. Liu et al., 2023). Although the main instrument only consists of two questions, the use of Cronbach's alpha remains representative and strong because both questions are broken down into 12 sub-questions with separate scores for indicators a to f which function as analytical items. The internal consistency of the measurement tool was established, yielding Cronbach's alpha coefficients of 0.77 for the pre-test and 0.89 for the post-test. These figures surpass the 0.60 minimum threshold for acceptable reliability recommended by Hair et al. (2010), thereby confirming the instrument's consistency.

After establishing that the pre-test and post-test questions were both valid and reliable, an analysis of the discrimination index was performed. In the pre-test, both questions were categorized as moderate. In the post-test, question two remained in the moderate range, while question three was rated as good. Concerning their difficulty, both the pre-test and post-test questions were deemed moderate. As a result, following the assessments of validity, reliability, discrimination index, and difficulty level, the pre-test and post-test questions were deemed appropriate for research purposes.

Data Analyze

Data analysis in this study covers the validity, practicality, and the initial effectiveness aspects of the Geoarcala game learning media. The validity of the material was assessed by

three material expert validators consisting of two lecturers and one mathematics teacher, while the validity of the media was assessed by four media expert validators. The practicality aspect was assessed by one mathematics teacher and students during the implementation stage. Testing took place through a small group that included eight students and a larger group involving all the Class IX A students from State Junior High School 1 Salaman.

The methods used for data analysis include both number-based and descriptive analysis. The numerical data comes from the evaluations made by the experts, teachers, and students, while the descriptive data consists of feedback, suggestions, and critiques from these same groups, which are used to improve the product. The validity of the media is judged based on the evaluations from both material and media experts. A media tool is seen as valid if it fulfills the set standards as detailed in Table 2. The method used to calculate the validity of both the content and media follows the formula outlined by Riduwan (2018).

$$V = \frac{Total\ score\ per\ indicator}{Total\ maximum\ score\ of\ indicators} \times 100\%$$

Table 2. Validity Level Criteria

Validity Percentage	Validity Level
$80\% < V \leq 100\%$	Very Valid
$60\% < V \leq 80\%$	Valid
$40\% < V \leq 60\%$	Quite Valid
$20\% < V \leq 40\%$	Invalid
$0\% \leq V \leq 20\%$	Very Invalid

If the minimum V index value is included in the valid criteria, the learning media is appropriate for usage (Riduwan, 2018). Thus, if the Geoarcala Game meets the minimum valid standards set by material and media specialists, it is deemed acceptable for usage. The media is said to be practical from a practical standpoint if it satisfies the assessment criteria established by Class IX A pupils and teachers as research participants. The formula for calculating practicality is as follows (Riduwan, 2018).

$$Practicality\ Level\ \ (p) = \frac{\sum Obtained\ score}{\sum Criteria\ score} \times 100\%$$

The results of the practicality percentage are classified in Table 3 which is adapted from Riduwan (2018).

Table 3. Practicality Criteria

Practicality Percentage	Criteria
$80\% < p \leq 100\%$	Very Practical
$60\% < p \leq 80\%$	Practical
$40\% < p \leq 60\%$	Quite Practical
$20\% < p \leq 40\%$	Less Practical
$0\% \leq p \leq 20\%$	Not Practical

The Geoarcala game is said to be useful to use if it satisfies the minimum practical requirements established by instructors and students, as the minimum practicality percentage for learning media is stated to be over 60% (Riduwan, 2018). The Lilliefors test was used to conduct a normality test for the potential initial effectiveness factor. The difference in the average critical thinking ability of students after receiving therapy using the created learning media was then assessed using a paired-samples t-test as part of the hypothesis testing. The degree of improvement is determined by an N-Gain test if a difference is discovered. According to (Hake, 1998), the following equation is used.

$$g = \frac{posttest\ score - pretest\ score}{maximum\ score - pretest\ score}$$

Furthermore, the N-Gain value criteria are grouped in Table 4 according to Hake (1998).

Table 4. N-Gain Score Criteria

Gain Value (g)	Criteria
$0{,}70 \leq g \leq 1{,}00$	High
$0{,}30 \leq g < 0{,}70$	Medium
$0{,}00 \leq g < 0{,}30$	Low

According to Hake (1998), the acquisition of N-Gain in the medium to high range is evidence of successful learning. As a result, the Geoarcala game is considered successful if the N-Gain number is in the middle range or above. Furthermore, to determine how much influence learning using the Geoarcala game has on students' critical thinking ability, the Cohen's d effect size test can be used. This value indicates the level of effectiveness of the treatment, which is categorized into six (Sawilowsky, 2009), namely very small effects $(0.01 \leq d < 0.2)$, small $(0{,}2 \leq d < 0.5)$, medium $(0.5 \leq d < 0.8)$, large $(0.8 \leq d < 1.2)$, very large $(1.2 \leq d < 2.0)$ and huge $(d \geq 2.0)$. The Cohen's d effect size calculation is as follows (Cohen, 1988).

$$d = \frac{M_1 - M_2}{SD_{pooled}}$$

Note:

M_1 : average post-test score
M_2 : average pre-test score
SD_{pooled} : pooled standard deviation.

RESULTS AND DISCUSSION

The development of the learning medium in this study was systematically guided by the ADDIE instructional design framework. This approach directed the research procedures through a sequence of analyzing needs, designing the prototype, developing the product, implementing it in the classroom, and evaluating its initial effectiveness.

Analysis

The analysis stage involved talking to ninth-grade math teachers at State Junior High School 1 Salaman to learn about the curriculum, learning goals, and objectives for the second semester. The findings showed that the school was using the Independent Curriculum (Kurikulum Merdeka), which concentrated on the learning outcomes and objectives regarding the surface area and volume of cylinders. Additionally, discussions with the teachers indicated that students faced significant challenges when it came to understanding cylinders. They found it hard to grasp the problem's context and convert it into mathematical terms.

A needs analysis revealed that 52% of students still struggled to analyze and solve complex problems related to cylinders. Furthermore, the lecture method alone was deemed insufficient in enhancing students' critical thinking ability. Therefore, teachers sought interactive and engaging learning media to encourage students to be more active in analyzing and evaluating information.

The review of accessible resources examined different factors that aid the learning process. Regarding content materials, mathematics textbooks were present, acting as the main reference for learning. Additionally, the school benefited from technological resources, including electricity, projectors, and internet connectivity, along with sufficient classroom facilities to enhance the learning environment. The findings from the analysis indicate a need to create contextual learning materials to assist in the understanding of cylinder concepts and to promote the enhancement of critical thinking skills.

Design

At this stage, the analysis results will be translated into a plan. The design phase aims to produce a product that can be used to support the learning process. The result of this design process is the Geoarcala game design, which was achieved through the following steps.

1. Determine development goals and learning objectives
   The development of the Roblox Geoarcala game integrated with ethnomathematics aims to enhancing students' critical thinking ability, particularly regarding the topic of cylindrical solids. The learning objectives for the cylinder material contained in the Geoarcala game are that students can calculate the surface area and volume of cylinders correctly, students can apply the concept of surface area and volume of cylinders in practical everyday situations correctly, and students are able to explain the effect of proportional changes in cylindrical solids on length, angle size, area and volume correctly.
2. Designing Products
   Next, various supporting materials needed for game development were designed and developed, such as images, learning materials, three-dimensional models, and game maps. This stage also included gathering supporting references and designing supporting instruments, such as critical thinking ability tests in the form of pre-test and post-test, media validation questionnaires, student and teacher response questionnaires, teaching modules, and observation sheets for learning implementation.
3. Storyboard Making
   The next step is to design a storyboard to serve as a reference during the Geoarcala game development process. The storyboard is designed in visual form, consisting of a story or sketch depicting the sequence of activities and user interactions within the game, allowing for a systematic and engaging presentation of the material.

Development

At this stage, the Geoarcala game was developed using Roblox Studio according to the pre-designed storyboard. Supporting materials, such as images, were created using Canva and CorelDraw, while the three-dimensional temple model was developed using SketchUp. Next, the game map and learning materials were integrated directly into Roblox Studio. The game layout and surroundings of Geoarcala can be seen in Figures 1 and 2.

Figure 2. Game environment view at Ngawen Tample

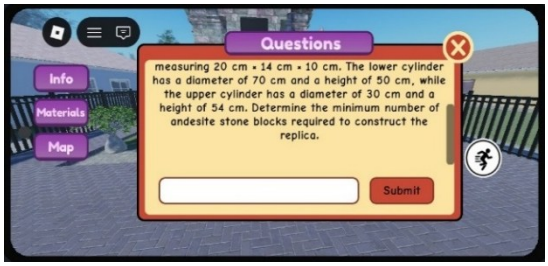

Figure 3. The interface display of one of the questions at Candi Pawon

Upon completion of the development process, the product underwent validation by subject matter experts in both material and media to evaluate the effectiveness of the learning resources through an assessment questionnaire. The validation by material experts involved three validators consisting of two university lecturers specializing in geometry material and one Mathematics subject teacher. This assessment utilized a questionnaire comprising 15 questions. In contrast, the validation conducted by media experts involved four lecturers with specialization in multimedia, using a questionnaire containing 11 questions. A summary of the validation findings from both material and media experts is provided in the table below.

Table 5. Recapitulation of the results of the material expert assessment

No	Assessment Aspect	Score	Criteria
1	Learning Aspect	85.00%	Very Valid

No	Assessment Aspect	Score	Criteria
2	Material Substance Aspect	83.81%	Very Valid
3	Language Aspect	86.67%	Very Valid
	Average	85.16%	Very Valid

According to the assessment results by material specialists in Table 5, the average validity score was 85.16%, which is classified as very valid. The information provided in the Geoarcala game successfully addresses the topics of language use, material content, and learning goals, as seen by this. The material was deemed to align with the learning objectives, the validity of the mathematical concepts, and its integration with the critical thinking ability indicators to be developed.

Table 6. Recapitulation of media expert assessment results

No	Assessment Aspect	Score	Criteria
1	Media Engineering Aspect	86.25%	Very Valid
2	Visual Communication Aspect	75.00%	Valid
3	Ethnomathematics Aspect	80.00%	Valid
	Average	80.42%	Valid

Additionally, according to Table 6, the evaluation results from media specialists reveal an average score of 80. 42%, which meets valid criteria. The media engineering aspect obtained a very valid category, which indicates that the Geoarcala game has been designed with a good system structure and is easy to operate. Meanwhile, the visual communication and ethnomathematics aspects are in the valid category, which indicates that the visual display and integration of ethnomathematics elements are appropriate, although there is still room for improvement. The validity of this media is demonstrated through the attractive media display design, ease of use of buttons, presentation of ethnomathematics elements in an interesting media, and the media's ability to present material clearly.

The evaluation findings suggest that the created learning media satisfies the criteria necessary for its use in the implementation phase. This conclusion aligns with the views of Akker et al., (2006), who pointed out that expert evaluations are essential in the creation of learning media to evaluate aspects such as design feasibility, presentation clarity, and usability prior to implementation. Moreover, Branch, (2009) highlighted that effective learning media must be capable of supporting the achievement of educational goals efficiently.

Nevertheless, experts still provided several comments and suggestions for improvement to enhance the quality of the learning media. Comments or suggestions from material experts included the need to add variety to the question format, from multiple-choice to short answer. Furthermore, it was suggested to complete the presented formulas, improve the illustrations of cylinder parts, and align the practice questions with indicators of critical thinking ability. Meanwhile, suggestions from media experts included the need for more detailed user instructions, a more expansive layout of questions and materials, and the use of consistent font sizes to improve readability.

As a follow-up to this feedback, several improvements were made to optimize the learning media. The Geoarcala game's display was made more consistent to facilitate readability and ease of use. Moreover, to foster the development of critical thinking ability, the questions presented were structured based on critical thinking ability indicators. The Geoarcala game is also equipped with stimulus questions that encourage students to think critically. This aligns with the views of Kanat & Fulya, (2025) who noted that the use of question-posing strategies in learning has been proven to improve students' critical thinking behavior by increasing cognitive engagement. Here is an example of a trigger question used in the Geoarcala game.

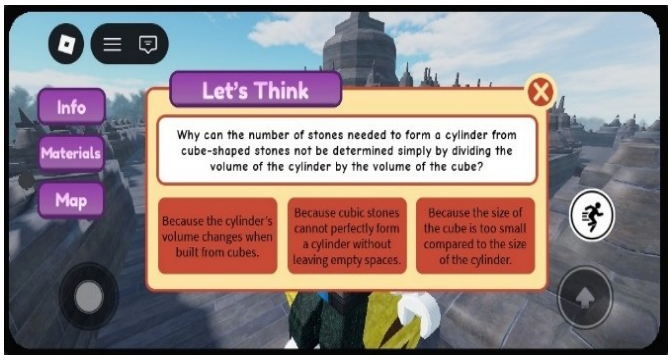

Figure 4. Stimulus question in geoarcala game

Following enhancements to the media guided by expert feedback, a small-group trial was conducted. The purpose of this trial was to assess the feasibility of the learning media on a limited level prior to its deployment in the implementation phase. Table 7 provides a summary of the learning media's practicality based on responses from student questionnaires.

Table 7. Recapitulation of results of student response to questionnaire

Aspect	Score	Criteria
Ease of Use	79.17%	Practical
Time and Energy Efficiency	83.33%	Very Practical
Learning Support	82.50%	Very Practical
Attractiveness and Convenience	81.25%	Very Practical
Average	81.56%	Very Practical

According to the evaluation results in Table 7, the Geoarcala game received an average score of 81.56% based on the criterion of being highly practical. According to this outcome, the created learning material is user-friendly, effective in terms of time and energy, facilitates the learning process, and is aesthetically pleasing and comfortable. According to Nieveen (1999), the usability of a product development is determined by how well users can utilize it in accordance with the developer's goals. Therefore, the Geoarcala game is deemed worthy of being tested in the following round.

However, students also provided several suggestions for improving the media. These suggestions included the need to add several features to simplify gameplay and the addition of ornaments to enhance the visual appeal of Geoarcala. Hence, feedback from students ought to be regarded as a foundation for refining the educational media.

Implementation

In the stage of putting into action, the Geoarcala learning tool was introduced to every student in class IX A. This stage aims to determine the initial effectiveness of using the Geoarcala game on a wider scale, and to observe its impact on students' learning results in a more detailed and inclusive learning setting.

Figure 5. Using the Geoarcala game in learning

During the implementation stage, students initially took a pre-test to assess their starting skills before engaging with the Geoarcala game. Following this, the educational process was conducted using the Geoarcala game as a tool for learning. Once the learning activities concluded, both students and teachers were requested to fill out a response questionnaire to evaluate the practicality of the created learning medium. The implementation stage ended with a post-test to evaluate the students' knowledge after their experience with the Geoarcala game.

Evaluation

After the entire learning process is completed in class, the next stage is to conduct an evaluation. The goal of this stage is to measure the initial effectiveness of the Geoarcala game in enhancing critical thinking ability. Based on the results of measurements on 23 students, the average pre-test score was 28.91 (SD = 6.69) which reflects the students' initial abilities before using the Geoarcala game. Meanwhile, the average post-test score was 50 (SD = 11.97) after learning using the developed media. These findings suggest that test scores improved before and after utilizing the Geoarcala game, even if the average final score did not satisfy the learning objective achievement criteria (KKTP) established by the institution.

The initial effectiveness assessment was then analyzed by comparing pre-test and post-test scores using a paired sample t-test. Prior to the test, a normality test was conducted to meet the assumptions of the paired sample t-test. Based on the results of the normality test using the Lilliefors test, the pre-test and post-test scores were normally distributed. Therefore, the analysis continued with a paired sample t-test.

Table 8. Paired samples t-test result

Pair 1	Mean	SD	SE	95% Conf. Interval		t	df	Sig.
				Lower	Upper			
Pretest - Posttest	-21.09	9.47	1.97	-25.18	-16.99	-10.68	22	<.001

The results of the inferential analysis using the paired sample t-test showed that there was a statistically significant difference in the increase in critical thinking ability between the pre-test and post-test results, with t(22) = 10.68 and p = 0.001. This significance value, which is much smaller than the alpha limit (0.05), confirms that the increase in scores did not occur by chance, but rather occurred due to the influence of media use on students' cognitive abilities. Although the t-test results indicated a statistically significant difference, calculating the effect size remains necessary to measure the actual magnitude of this effect using Cohen's guidelines, as shown in Table 9.

Table 9. Paired samples effect sizes

Pair 1		Standardizer[a]	Point Estimate	95% Conf. Interval	
				Lower	Upper
Pre – Pos Test	Cohen's d	9.46963	-2.227	-2.990	-1.449
	Hedges' correction	9.63496	-2.189	-2.939	-1.424

Then, to assess the extent of the effect or the strength of the media intervention's influence, a calculation of the effect size was conducted. Based on Table 9, Cohen's d test yielded a value of d = 2.227. Based on the criteria for interpreting effect sizes (Sawilowsky, 2009), this value is greater than 2.0, indicating that the intervention using the Geoarcala game had a huge impact on improving students' critical thinking ability.

Next, to measure the potential initial effectiveness of the learning media in improving students' critical thinking ability, an N-Gain test was performed. The results of the N-Gain test are presented in Table 10.

Table 10. N-gain test result

Average N-Gain Score	Criteria
0.30	Medium

Based on Table 8, the results from the N-Gain calculations show an average of 0.30, which falls into the moderate range based on Hake (1998) classification. The moderate N-Gain suggests that the Geoarcala game positively influences the enhancement of students' critical thinking ability, although this increase is not yet in the high category. To understand more deeply which aspects of critical thinking are most impacted by the Geoarcala media intervention, an analysis was conducted at the indicator level. Figure 6 displays the average scores for each critical thinking indicator from the pre-test and post-test.

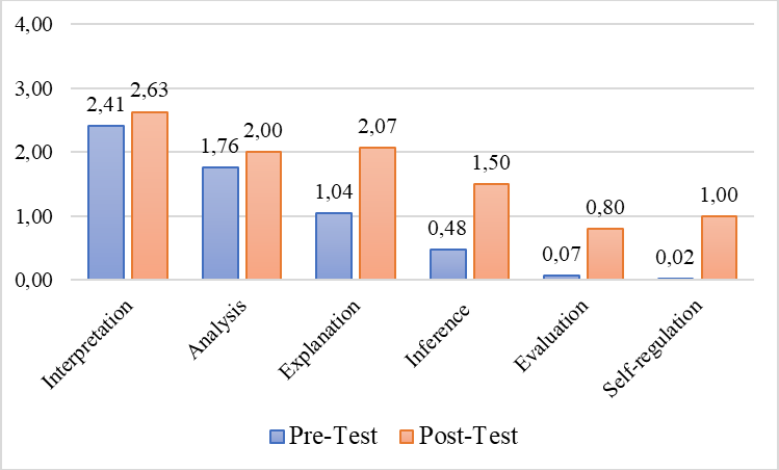

Figure 6. Comparison of average scores per critical thinking ability indicator

Based on Figure 6, score increases occurred across all dimensions of critical thinking. Upon closer examination, the interpretation and analysis indicators had relatively good initial scores and experienced steady improvement. The most prominent finding was a significant increase in the explanation indicator, which increased by 1.03 and inference by 1.02. Conversely, although the evaluation and self-regulation indicators improved after the treatment, both indicators still recorded the lower final scores than the rest of the indicators. These findings indicate that media use has varying reinforcing effects on students' cognitive levels.

The average post-test score, which fell short of the Learning Objective Achievement Criteria (KKTP) with moderate N-Gain, can be explained through analysis during the field implementation phase. The low score achievement is directly related to the evaluation and self-regulation indicators. The trial was conducted following the standard allocation of one lesson hour at the high school level, which is 40 minutes. The exploration and mission completion process within the media took up the majority of the time, approximately 30 minutes. As a result, the remaining time allocated for the next phase, namely feedback and in-depth discussion, was very minimal. In fact, the feedback and discussion phase after the game is the primary space for students to re-evaluate the accuracy of the completion steps and practice their self-regulation. This limited time for the feedback phase confirms research that suggests that without sufficient time to deepen the material, learning outcomes can potentially decline (A. Liu et al., 2023; Wedel, 2021).

On the other hand, the surge in success in the other four cognitive indicators was not coincidental, but rather supported by the characteristics of the learning media developed. The three-dimensional visual presentation of the temple building in the game realistically helped students visualize the parts that represent the cylindrical geometric shape. This facilitated a more concrete understanding of geometric concepts and had a direct impact on strengthening the interpretation and analysis indicators (Akbar, et al., 2025)

Meanwhile, the significant increase in scores on the explanation and inference indicators is highly relevant to the game's in-game trigger question interface. This feature emerges when students interact with temple objects, forcing them to formulate logical reasoning and helping

them draw conclusions from real-world contexts into mathematical models before performing calculations. Furthermore, the structured practice questions, packaged with ethnomathematical contexts from Ngawen, Mendut, Pawon, and Borobudur Temples, have been shown to provide meaningful learning experiences that stimulate students' analytical reasoning (Agustina et al., 2024). Finally, interaction-based challenges, where students are asked to independently search for and identify parts of the temple that represent a cylinder, generate trigger questions and practice questions. This interaction stimulates students' analytical skills in identifying appropriate geometric shapes. Such alignment between gameplay mechanics and cognitive demands enables measurable advancements in students' critical thinking competencies.

In addition to evaluating the initial effectiveness of the Geoarcala game, it is essential to analyze the practicality of utilizing the learning media. Learning media is deemed practical if it can be easily utilized by students in alignment with the intentions and objectives set by the developers (Nieveen, 1999). The outcomes of the practicality analysis of the learning media, informed by student questionnaire responses, are illustrated in Table 11.

Table 11. Recapitulation of student and teacher response analysis

Aspect	Students	Teacher
Ease of Use	85,80%	86,67%
Time and Energy Efficiency	78,55%	80,00%
Learning Support	86,26%	86,67%
Attractiveness and Convenience	84,78%	86,67%
Average	83,85%	85,00%
Overall Average	84,42%	
Criteria	Very Practical	

According to the findings of the student and teacher questionnaire analysis presented in Table 9, the Geoarcala game has a very high level of practicality. According to student assessments, the average score was 83.85%, while teacher assessments yielded an average score of 85%, both of which are well within the highly practical standards. The Geoarcala game is shown by these findings to be user-friendly, time-saving, conducive to learning, and enjoyable to play.

The congruence between student and instructor assessments further demonstrates that the learning tools created are both simple for students to utilize and useful for teachers to integrate into classroom instruction. As a result, we can say that the Geoarcala game satisfies the usability requirements and may be utilized as a teaching tool. As a result, the Geoarcala game, which incorporates ethnomathematics from temples in Magelang, satisfies the requirements for validity and practicality and shows promise for initially helping to enhance students' critical thinking ability.

Numerous prior studies have demonstrated that creating ethnomathematics-based learning tools can enhance pupils' capacity for critical thinking, and the findings of this study support those earlier findings. According to Fitri, et al. (2025), an ethnomathematics approach that connects learning to the local culture improves student participation in critical thinking exercises by making learning more pertinent and intriguing. According to Pramasdyasari, Aini & Setyawati (2024), the inclusion of cultural components in instructional media enhances the learning experience and has a beneficial impact on the growth of students' critical thinking ability. This perspective is consistent with their findings. These results reinforce the notion that incorporating ethnomathematics into instructional materials is a successful strategy for fostering critical thinking ability.

The use of Roblox-based learning media has a positive impact on student engagement in the learning process. During learning using the Geoarcala game, students responded positively, stating that the game was fun, interesting, and challenging, thus encouraging their active engagement. This condition indicates that Roblox-based games can have a beneficial impact on education (Meier et al., 2020). Furthermore, Roblox has the potential to enhance student

enthusiasm and encourage active learning (Han et al., 2023). In addition, Roblox games promote experiential and exploratory learning, which might enhance students' conceptual comprehension and visualization abilities (Kang et al., 2022). In conclusion, learning resources on Roblox not only boost student enthusiasm and participation but also foster critical thinking. Students can more easily recognize and evaluate geometric things with the help of media that actively involves them and allows them to interactively visualize geometric objects (Akbar et al., 2025). In consequence, Roblox-based instructional games have great promise for fostering students' critical thinking ability, particularly in the interpretation indicator, which is a key element of critical thinking ability.

In comparison to earlier studies, the integration of the 3D Roblox gaming platform with a local ethnomathematics approach as a single interactive medium, which is a field that has received little attention in mathematics education research, is what sets this research apart. But there are a number of methodological and practical drawbacks to this research. The effectiveness test has limitations such as its restricted implementation period, its lack of a control group design, and its focus on the cylindrical geometry material with a rather tiny sample size. Notwithstanding these constraints, the empirical results of this work nonetheless advance the body of knowledge on creating creative mathematics media that integrates local cultural history with digital technology.

CONCLUSION

This research has successfully developed a Roblox-based Geoarcala educational game that integrates ethnomathematic elements from temples in the Magelang region. Expert validation and field practicality tests confirm that this product not only meets the standards for media engineering and geometry content, but also demonstrates considerable practicality regarding user-friendliness, efficiency in time and energy, support for learning, and attractiveness for both students and educators. Furthermore, the use of this media demonstrates promising initial effectiveness in facilitating the improvement of students' critical thinking ability, with the most significant increase in cognitive achievement observed in the explanation and inference indicators thanks to the support of interactive interface features and prompting questions.

The findings of this study imply that learning media integrated with ethnomathematics and interactive media have the potential to be an alternative solution to address students' difficulties in understanding abstract mathematical problems. However, the moderate improvement in critical thinking ability obtained in this study reflects implementation limitations. Therefore, claims of effectiveness in this study are preliminary and cannot be generalized as a definitive cause-and-effect relationship.

RECOMMENDATION

The developed learning media still has the potential for further refinement, both in terms of features, appearance, and the development of the scope of other circular solids, so that it can produce more optimal learning media. Furthermore, further research is recommended to conduct effectiveness trials on a wider scale using a larger sample and involving a control group. Furthermore, future media implementation needs to be allocated over several sessions to overcome the transition of technology adaptation in students, so that the use of game features can be fully focused on achieving critical thinking ability.

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AUTHOR CONTRIBUTIONS STATEMENT

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author [FA]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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