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Empirical Paper

Development, Validity, and Effectiveness of an Ethnomathematics-Based Learning Medium Using Menara Kudus to Improve Fifth-Grade Students' Understanding of Quadrilateral Area

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Abstract

Purpose: This study aimed to develop and evaluate an ethnomathematics-based interactive learning medium using the Menara Kudus landmark to improve fifth-grade students' conceptual understanding of quadrilateral area, addressing the gap between technology-focused and culturally grounded approaches in mathematics instruction.

Methodology: A Research and Development (R&D) design based on the Borg and Gall model, as adapted by Sugiyono, was employed, encompassing needs analysis, product design, expert validation, revision, and field testing. Participants comprised 28 fifth-grade students (experimental group) and 27 students (control group) from two Madrasah Ibtidaiyah in Kudus. Data were gathered through observation, interviews, expert and student validation questionnaires, and a pre-test–post-test instrument, and were then analysed descriptively and using a gain-score comparison.

Results: The developed medium, comprising an interactive module, student worksheet, teaching materials, and a snake-and-ladder game, achieved high validity (91% material, 78% media, 90% language) and strong practicality (89% student response). The experimental group recorded a higher normalised gain (57%, moderate category) than the control group (43%), though this difference was descriptive rather than statistically confirmed.

Novelty and Contribution: Unlike prior studies that treat multimedia design and ethnomathematics separately, this research integrates both into a single validated instructional product centred on a specific local landmark, offering a replicable model for culturally embedded digital learning design.

Practical and Social Implications: The medium equips teachers with a ready-to-use, culturally contextualised tool for teaching geometry, while reinforcing local cultural identity and heritage awareness among students, supporting broader efforts to make mathematics education more meaningful, equitable, and contextually relevant.

Keywords: Ethnomathematics; Interactive Learning Media; Conceptual Understanding; Quadrilateral Area; Research and Development

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1 Introduction

Mathematics education at the elementary level continues to face persistent global challenges in fostering students' conceptual understanding and higher-order mathematical thinking skills (Mullis et al., 2020). Evidence from the Programme for International Student Assessment (PISA) conducted by the Organisation for Economic Co-operation and Development (OECD) indicates that a substantial proportion of students across participating countries demonstrate proficiency primarily at procedural levels, with limited performance in complex reasoning and mathematical modelling (OECD, 2023). Similar trends are reported in international large-scale assessments such as TIMSS, which highlight persistent difficulties in geometry and measurement domains (Mullis et al., 2020). These findings suggest that mathematics instruction remains predominantly focused on algorithmic execution and formula memorisation rather than on deep conceptual construction and transfer-oriented learning (Hattie, 2023).

In response to the demands of 21st-century education, digital transformation has significantly reshaped instructional expectations, emphasising interactive, student-centred, and technology-enhanced learning environments (Lebona et al., 2025; Tondeur et al., 2023). Research published in Computers & Education demonstrates that multimedia learning environments grounded in cognitive load theory enhance students' conceptual retention and problem-solving abilities (Ran et al.., 2022). Furthermore, digital interactive tools positively influence mathematics achievement when designed with pedagogical alignment (Schindler et al., 2022; Hillmayr et al., 2021). However, scholars caution that technology alone does not guarantee meaningful learning unless integrated with contextual and culturally relevant pedagogical approaches (Voogt et al., 2015).

Ethnomathematics has gained increasing scholarly attention as a culturally responsive framework that connects formal mathematical concepts with local knowledge systems and community practices (Rosa & Orey, 2020). Studies published in Educational Studies in Mathematics demonstrate that culturally grounded instruction enhances meaning-making processes, identity affirmation, and conceptual coherence (Mulenga et al., 2022). Similarly, contextualised mathematics instruction improves student engagement and supports deeper conceptual understanding (Trinick et al., 2026). Culturally responsive pedagogy in mathematics is also associated with increased motivation and equitable learning outcomes (Gay, 2021).

At the national level, Indonesian students' mathematics literacy performance remains below the OECD average, particularly in geometry and measurement topics (OECD, 2023). Geometry learning, especially the concept of quadrilateral area, requires relational reasoning, spatial visualisation, and understanding of structural properties (Marchand et al., 2024). Research indicates that students often memorise area formulas without comprehending their derivation or geometric relationships, resulting in fragile knowledge structures (Li et al., 2025; Hattie, 2023).

In Kudus Regency, the geometric architecture of Menara Kudus embodies authentic quadrilateral forms and proportional structures that can serve as meaningful contextual resources in geometry instruction (Priestley & Philippou, 2018). Integrating such cultural artefacts into interactive digital learning environments offers a promising strategy to bridge abstract mathematical concepts with students' lived experiences (Rosa & Orey, 2020; Voogt et al., 2015). The convergence of multimedia learning principles and ethnomathematical context thus represents an innovative approach aligned with global trends in culturally responsive and technology-enhanced education (Trinick et al., 2026).

Although extensive research supports the effectiveness of interactive multimedia learning in improving conceptual understanding (Li et al., 2025) and other studies validate the pedagogical value of ethnomathematics in enhancing contextual relevance and engagement (Rosa & Orey, 2020), these frameworks are often implemented independently. Technology-focused studies frequently emphasise design features and engagement metrics without integrating culturally grounded content (Schindler et al., 2022). Conversely, ethnomathematics research often prioritises contextual pedagogy without incorporating systematic multimedia design and interactivity (Trinick et al., 2026). Furthermore, empirical studies specifically addressing the development and validation of ethnomathematics-based interactive teaching media targeting quadrilateral area concepts at the elementary level remain scarce (OECD, 2023). This gap indicates the need for an integrated instructional design that combines multimedia cognitive principles with culturally responsive pedagogy while systematically measuring conceptual understanding outcomes.

Based on the identified research gap, this study aims to:

i. Develop an ethnomathematics-based interactive teaching medium for quadrilateral area concepts in fifth-grade elementary mathematics

ii. Examine the validity and practicality of the developed instructional media through expert validation and classroom implementation

iii. Evaluate the effectiveness of the media in improving students' conceptual understanding using empirical measurement and comparative analysis

Theoretically, this study contributes to mathematics education literature by integrating multimedia cognitive theory, culturally responsive pedagogy, and ethnomathematics into a unified instructional design model. Practically, it provides teachers with an innovative and culturally contextualised digital learning resource aligned with 21st-century competencies. At the policy level, the study supports national and global efforts to enhance mathematics literacy through contextualised and technology-integrated instructional innovation.

2 Methodology

This study employed a Research and Development (R&D) approach to develop and evaluate an ethnomathematics-based interactive learning medium for Grade 5 mathematics instruction on quadrilateral area, following the Borg and Gall model, as adapted by Sugiyono, for classroom-based educational research (Dalam Sugiyono, 2017; Putri, 2023). The adapted model retains the original iterative philosophy of design, validation, and field testing while simplifying implementation for a single-topic classroom study. Of the model's full ten stages, this study was limited to needs analysis, product design, expert validation, revision, and field testing; the mass production and large-scale dissemination stages were not undertaken due to the scope of the research.

2.1 Research Procedure

The development process began with a needs analysis conducted through classroom observation and interviews with Grade 5 teachers, which indicated that mathematics instruction remained teacher-centred and textbook-reliant, and that students experienced particular difficulty with quadrilateral area concepts. These findings informed the design of the product, which integrated the local cultural landmark, Menara Kudus, into the mathematical content. The final product consisted of an interactive teaching module, a student worksheet (LKPD), supporting teaching materials, and an ethnomathematics-themed snake-and-ladder game. The prototype was then submitted for expert validation and, following revision, implemented in a field trial to evaluate its effectiveness.

2.2 Participants

Participants consisted of Grade 5 students from two Madrasah Ibtidaiyah (Islamic elementary schools) in Kudus. The experimental group comprised 28 students from MI NU Al-Azhariyyah, who received instruction using the developed media, while the control group comprised 27 students from MI NU Miftahul Huda 01, who received conventional instruction. Three experts — one each in mathematics content, instructional media, and language — served as validators of the product prototype.

2.3 Instruments and Data Collection

Data were collected through classroom observation, semi-structured teacher interviews, expert validation questionnaires, a student response questionnaire, and a learning outcomes test.

Observation and interviews were used during the needs-analysis stage to characterise existing classroom practice. Expert validation questionnaires, using a four-point Likert scale ranging from "very feasible" to "less feasible," were administered separately to the material, media, and language experts to assess the feasibility of the developed product. A parallel student response questionnaire captured learner perceptions of the product's practicality.

Learning effectiveness was assessed using a 20-item multiple-choice test measuring students' conceptual understanding of quadrilateral area, administered as a pre-test before the intervention and a post-test afterwards to both the experimental and control groups.

2.4 Data Analysis

Qualitative data from observations and interviews were summarised descriptively to characterise instructional needs and inform product design.

Quantitative data from the expert and student validation questionnaires were analysed by converting Likert-scale scores into mean scores and percentages, which were then classified into feasibility categories (e.g., "valid," "very valid") based on standard interpretation thresholds for product feasibility.

Learning effectiveness was analysed by comparing pre-test and post-test mean scores for the experimental and control groups, calculating the gain (post-test mean minus pre-test mean) for each group, and computing a normalised gain percentage to characterise the relative improvement between groups.

3 Result

3.1 Development of the Ethnomathematics-Based Interactive Learning Medium

The development of the medium followed the Borg and Gall research and development (R&D) model, as adapted by Sugiyono, beginning with a needs analysis conducted through classroom observation and teacher interviews (Dalam Sugiyono, 2017). This analysis revealed that Grade 5 mathematics instruction remained teacher-centred and textbook-reliant, and that students experienced particular difficulty understanding quadrilateral area concepts.

Based on these findings, an ethnomathematics-based interactive learning medium was constructed around the local cultural landmark Menara Kudus to enhance conceptual understanding of quadrilateral area while preserving cultural awareness. The final product consisted of four components: an interactive teaching module, a student worksheet (LKPD), supporting teaching materials, and an ethnomathematics-themed snake-and-ladder game. Together, these components directly satisfy the first research objective of developing an ethnomathematics-based interactive teaching medium for quadrilateral area concepts in fifth-grade mathematics.

3.2 Validity and Practicality of the Developed Medium (addresses Objective 2)

The developed medium was validated by three experts, one each in mathematics content, instructional media, and language, using a four-point Likert-scale questionnaire. Student practicality was assessed through a parallel-response questionnaire administered after classroom implementation.

Table 1 Interactive Teaching Media Validation Summary

Aspect	Mean Score	Percentage	Category
Material expert	3.64	91%	Very valid
Media expert	3.12	78%	Valid
Language expert	3.62	90%	Very valid
Student response	3.57	89%	Very good

All three expert domains rated the product as valid or very valid, and student responses indicated a very good level of practicality. Component-level breakdowns are provided in Tables 2–4.

Table 2 Material Expert Feasibility

Component	Percentage	Category
Content feasibility	96%	Very feasible
Presentation	75%	Feasible
Graphics	100%	Very feasible
Total	91%	Very feasible

Table 3 Media Expert Feasibility

Component	Percentage	Category
Size	75%	Feasible
Cover design	75%	Feasible
Content illustration	83%	Very feasible
Layout design	79%	Feasible
Graphics	74%	Feasible
Total	78%	Feasible

Table 4 Language Feasibility

Component	Percentage	Category
Language	91%	Very Feasible

Taken together, these results indicate that the developed medium meets the criteria of a valid and practical instructional product from both expert and student perspectives, addressing the second research objective.

3.3 Effectiveness of the Developed Medium (addresses Objective 3)

Effectiveness was examined by comparing pre-test and post-test scores of the experimental group (n = 28), which used the developed medium, with those of the control group (n = 27), which received conventional instruction.

Table 5 Comparison of Learning Outcomes

Group	Pre-test Mean	Post-test Mean	Gain	N-Gain (%)	Category
Experimental	56.78	81.42	24.64	57%	Moderate
Control	56.48	75.37	18.89	43%	Moderate

Both groups showed a moderate normalised gain according to standard N-Gain interpretation thresholds (Sukmawati et al., 2026), and the experimental group's gain (57%) was higher than that of the control group (43%). The experimental group also achieved a higher post-test mean score (81.42) than the control group (75.37). Together, these descriptive comparisons indicate that students who used the ethnomathematics-based interactive medium showed a numerically greater improvement in conceptual understanding of quadrilateral area than students who received conventional instruction, addressing the third research objective through empirical pre-test–post-test measurement and comparative analysis of gain scores between groups.

This comparison is descriptive rather than inferential: no statistical test of significance (e.g., independent-samples *t*-test) was conducted, so the observed difference in gain between groups should be interpreted as an indication of relative improvement rather than a confirmed statistically significant effect. This is noted as a direction for further analysis rather than a claim made by the present data.

4 Discussion

The identification of teacher-centred instruction and heavy textbook reliance as barriers to understanding quadrilateral area necessitated a shift toward contextualised pedagogy. Traditional methods often fail to bridge the gap between abstract formulas and students' lived experiences, leading to fragile knowledge structures (Mumu et al., 2026). Ethnomathematics addresses this by positioning mathematics as a socially constructed discipline rooted in cultural artefacts. By situating mathematics within Kudus' cultural landmarks, the developed medium shifts the pedagogical focus from passive reception to active meaning-making (Nst & Batubara, 2024).

The decision to integrate a module, student worksheets (LKPD), and teaching materials provides a structured framework for independent and guided exploration. These components directly address textbook reliance by allowing students to discover area concepts through the analysis of local motifs and architectural patterns. Such instructional tools are effective in bridging the persistent gap between formal school mathematics and culturally grounded cognition (Zainovi et al., 2025).

The snake-and-ladder game addresses limited engagement by introducing an interactive element that encourages social interaction and conceptual reinforcement. Game-based formats are pedagogically appropriate for elementary learners because they combine competition with cognitive challenge, reducing mathematics anxiety while allowing for meaningful repetition. This component complements the more formal materials by providing a space for students to practice and articulate their mathematical thinking through collaborative play, which is essential for establishing foundational reasoning skills (Utami et al., 2026). Evidence indicates that well-designed educational games provide psychologically safe environments that support both academic achievement and sustained learner engagement (Meylan, 2025).

The high scores from material and language experts suggest that the instructional core of the developed medium is pedagogically sound and appropriately tailored to the cognitive development of fifth-grade learners. These results indicate successful ethnomodelling, where mathematical concepts are accurately embedded within the cultural context of Menara Kudus while maintaining linguistic clarity (Mumu et al., 2026). However, the media validation score of 78% presents a significant deviation from the uniformly high results often reported in similar development studies. For instance, previous research on ethnomathematics-based modules and interactive media has yielded design and media scores consistently exceeding 90% (Mahardika et al., 2024; Yuliana et al., 2023). This discrepancy suggests that while the content is robust, the technological execution possesses distinct limitations.

Examining the component-level results reveals that graphics (74%) and layout (79%) are the primary areas requiring revision. For elementary students in the concrete operational stage, visual presentation is not a peripheral concern; it serves as a critical cognitive bridge (Mahardika et al., 2024). Research in multimedia learning emphasises that organised information and clear visual hierarchies are essential for reducing extraneous cognitive load (Hadiyanti et al., 2021).

The effectiveness finding revealed that the experimental group exhibited a numerically higher normalised gain compared to that observed in the control group. While both cohorts demonstrated moderate improvement according to standard interpretation thresholds, the descriptive disparity indicates a trend where the ethnomathematics-based medium supported a greater increase in post-test scores for quadrilateral area concepts. This result represents a descriptive pattern observed in the data rather than a confirmed statistically significant effect, as inferential tests were not conducted to verify if the difference occurred beyond chance.

The greater learning gains in the experimental group likely stem from the cultural relevance of Menara Kudus. By situating abstract geometry within a familiar architectural landmark, the medium provided cognitive anchors that facilitated the transition from intuitive to formal mathematical reasoning. This aligns with sociocultural constructivism, where meaning-making is enhanced when instruction connects formal concepts to familiar cultural activities and everyday experiences (Mumu et al., 2026). The interactive components, particularly the snake-and-ladder game, provided essential opportunities for active participation and repeated practice. Research suggests that game-based formats increase internal motivation and immersion, allowing students to consolidate skills through meaningful repetition without the anxiety often associated with conventional procedural instruction (Utami et al., 2026).

These findings indicate a pattern consistent with existing ethnomathematics research, which consistently reports measurable improvements in students' conceptual understanding when local artefacts are integrated into instruction (Mumu et al., 2026; Utami et al., 2026). However, the observed difference may reflect several interacting factors, such as increased student interest or the specific novelty of the interactive media, rather than the cultural context alone. Because the study utilised intact classes without inferential testing, the evidence remains suggestive rather than conclusive. Future research employing stronger experimental designs, such as randomised controlled trials and longitudinal analysis, is necessary to provide clearer evidence of causal effectiveness and to determine if these learning gains are sustained over time (Mumu et al., 2026).

5 Conclusion

This study successfully developed, validated, and tested an ethnomathematics-based interactive learning medium that integrates the cultural landmark, Menara Kudus, into fifth-grade instruction on quadrilateral area. Guided by the Borg and Gall R&D model as adapted by Sugiyono, the development process moved systematically from needs analysis through expert validation to field implementation, resulting in a coherent instructional package consisting of an interactive teaching module, a student worksheet, supporting materials, and a snake-and-ladder game. The findings demonstrate that the medium meets the criteria of a valid and practical instructional product. Expert validation confirmed strong feasibility in material content (91%) and language (90%), with media design rated feasible (78%), while students responded very positively to the product's usability and engagement (89%). In terms of effectiveness, the experimental group achieved a higher normalised learning gain (57%) than the control group (43%), suggesting that embedding mathematical concepts within a familiar cultural context can support deeper conceptual understanding compared to conventional instruction. However, because this comparison was descriptive rather than inferential, the observed advantage should be interpreted as indicative rather than conclusive. These results affirm that connecting abstract geometric reasoning to authentic, locally meaningful architectural forms provides students with cognitive anchors that ease the transition from concrete to formal mathematical thinking. The interactive game component further contributed by fostering motivation and reducing anxiety associated with procedural learning. Collectively, the study reinforces the value of combining multimedia design principles with culturally responsive pedagogy, rather than treating them as separate instructional strategies.

Social and Practical Implications

The findings carry direct practical value for elementary mathematics teaching. By producing a validated interactive module, student worksheet (LKPD), supporting materials, and an ethnomathematics-themed snake-and-ladder game, this study equips teachers with a ready-to-use instructional resource that shifts practice away from teacher-centred, textbook-reliant instruction toward active, exploratory learning. Because the medium integrates Menara Kudus, an authentic local landmark, into the teaching of quadrilateral area, teachers in Kudus and comparable regions can adopt or adapt the product without needing to design contextual materials from scratch, addressing a gap identified in the needs analysis where instruction remained procedural and abstract.

Socially, embedding a recognisable cultural artefact into formal mathematics content reinforces students' connection to their local heritage while they learn. This aligns mathematics instruction with sociocultural constructivist principles, allowing students to see mathematics as embedded in their own community rather than as a decontextualised, foreign discipline. The game-based component additionally supports collaborative learning and reduces the anxiety often associated with conventional procedural instruction, fostering a more positive social and emotional experience of mathematics in the classroom.

More broadly, the study demonstrates a workable strategy for reconciling two educational priorities that are often pursued separately: technology-enhanced instruction and culturally responsive pedagogy. For schools and communities seeking to strengthen both mathematical literacy and cultural identity simultaneously, this integrated model offers a practical template that can be replicated using other local cultural landmarks and mathematical topics beyond quadrilateral area.

Implications for Policy Formation

At the policy level, this study's findings support ongoing national and global efforts to improve mathematics literacy through contextualised, technology-integrated instructional innovation. The demonstrated success of embedding a local cultural landmark into a validated interactive medium suggests that curriculum policies could formally encourage or mandate the incorporation of ethnomathematics and regional cultural content into mathematics teaching materials, rather than leaving such integration to individual teacher initiative.

Limitations and Recommendations for Future Research

This study has several limitations that should be acknowledged. First, the R&D process was restricted to the stages of needs analysis, product design, expert validation, revision, and field testing; the mass production and large-scale dissemination stages of the Borg and Gall model were not undertaken, limiting claims about the medium's broader applicability. Second, the effectiveness analysis relied on intact classes from two different schools rather than random assignment, and the comparison between experimental and control groups was descriptive rather than inferential; no statistical significance test, such as an independent-samples t-test, was conducted. Consequently, the observed difference in learning gains should be interpreted as suggestive of relative improvement rather than as confirmed evidence of a causal effect. Third, the sample was relatively small and drawn from a single regional context, limiting generalizability to other populations or cultural settings.

For future research, studies should employ stronger experimental designs, including randomised controlled trials, larger and more diverse samples, and inferential statistical testing, to establish clearer causal evidence of the medium's effectiveness. Longitudinal designs are also recommended to determine whether observed learning gains are sustained over time rather than reflecting short-term novelty effects. Additionally, future studies could investigate which specific components — the module, worksheet, or game — contribute most to learning outcomes, and could extend the mass production and dissemination stages to evaluate scalability. Finally, revising the media design elements identified as weaker, particularly graphics and layout, and re-testing their impact would strengthen subsequent iterations of this instructional approach.

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Conflict of Interest

The authors declare no conflicts of interest.

Declaration of Use of Generative AI

Generative AI tools were used exclusively for layout formatting, paraphrasing, and grammar correction.

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