



## **Reconstructing Geometric Concepts through Uma Lengge: An Ethnomathematics-Based Design Study to Enhance Students' Contextual Problem-Solving Skills**

**Sudarsono<sup>1\*)</sup>, Nur Baeti<sup>2</sup>, Dewi Sartika<sup>3</sup>**

<sup>1,2,3</sup>Universitas Nggusuwaru, Indonesia

### **Abstract**

This study aimed to reconstruct geometric concepts through an ethnomathematical approach and examine its impact on students' contextual problem-solving skills, addressing the limited use of Design-Based Research (DBR) in this area. Using a DBR approach conducted through iterative phases of preliminary analysis, design, implementation, and reflection, the study involved 30 eighth-grade students at SMPN 1 Madapangga. Two implementation cycles were carried out: the first informed design revisions, while the second confirmed that the refined design had reached a stable, mature form. The learning design employed Uma Lengge, a traditional Bimanese (Mbojo) granary structure, as the cultural artefact for reconstructing solid geometry concepts. Data were collected through contextual problem-solving tests, classroom observations, interviews, and documentation and were analysed using a mixed-methods approach. Results showed a statistically significant improvement in students' contextual problem-solving skills ( $t(29) = 9.87$ ,  $p < 0.001$ ), with a large effect size (Cohen's  $d = 1.80$ , 95% CI [1.15, 2.46]) and a moderate average N-gain of 0.62. Students demonstrated improved abilities to understand problems, formulate mathematical models, apply geometric concepts, and interpret solutions, while observations and interviews indicated greater engagement and conceptual understanding. These findings demonstrate that culturally contextualised, iteratively refined learning designs can effectively reconstruct geometric concepts and enhance meaningful mathematical learning, contributing a practical DBR-based framework for culturally responsive mathematics education.

### **Keywords:**

Ethnomathematics; geometry learning; design-based research; conceptual reconstruction; contextual problem-solving

(\*) Corresponding Author: [sudarsonolanda123@gmail.com](mailto:sudarsonolanda123@gmail.com)

**How to Cite:** Sudarsono, S., Baeti, N., & Sartika, D. (2026). Reconstructing Geometric Concepts through Uma Lengge: An Ethnomathematics-Based Design Study to Enhance Students' Contextual Problem-Solving Skills. *Formatif : Jurnal Ilmiah Pendidikan MIPA*, 16(2), 319-334. <https://doi.org/10.30998/formatif.v16i2.3425>

## **INTRODUCTION**

Geometry is a fundamental domain of mathematics education that plays a crucial role in developing students' logical reasoning, spatial visualization, and problem-solving abilities. Through geometry, students learn to analyse shapes, patterns, measurements, and spatial relationships that are essential in both academic and real-life contexts. Geometry relies heavily on spatial visualization, orientation, relational thinking, and mental rotation skills (Fujita et al., 2020; Harris et al., 2025; Yu et al., 2022). Consequently, mastery of geometric concepts is considered essential for students in secondary education because strong spatial abilities are associated with better performance in geometry tasks and overall mathematical achievement (Adams et al., 2023; Clayton et al., 2023).

Despite its importance, geometry remains one of the most challenging areas of mathematics for many students. Learners frequently encounter difficulties in visualising geometric objects, identifying relationships among shapes, and applying geometric principles in contextual situations. The abstract nature of geometric concepts and limited opportunities to construct understanding through meaningful learning experiences often contribute to these challenges. Geometry involves idealized objects, such as points, lines, and solids, that are difficult to comprehend without appropriate models and representations (Jablonski, 2024). These difficulties are exacerbated by teacher-centred approaches that emphasize

formula memorization and procedural exercises, leading students to perceive geometry as abstract and disconnected from real-life situations.

Contextual problem-solving refers to an individual's ability to formulate, employ, and interpret mathematics in various real-world situations. According to the OECD PISA framework, mathematical problem-solving involves recognizing the role of mathematics in everyday contexts, translating real-life situations into mathematical representations, and using mathematical reasoning to make informed decisions (OECD, 2023). Students with strong contextual problem-solving skills are able to interpret authentic situations mathematically, formulate solution strategies, and evaluate the relevance of their solutions. However, this competence cannot be optimally developed when mathematics instruction lacks contextual relevance. Previous studies have shown that realistic problem-based learning and contextual learning materials are more effective in improving students' performance on applied mathematical tasks than conventional instructional approaches (Anugraheni et al., 2025; Sutarni et al., 2024).

Understanding how students develop contextual problem-solving skills through culturally meaningful geometry learning requires a broader theoretical perspective. Existing studies tend to explain learning outcomes using a single theoretical lens, which may not fully capture the interactions among learners, cultural contexts, and authentic learning situations. Therefore, this study is grounded in a theoretical triangulation framework consisting of constructivist theory, sociocultural theory, and situated learning theory. Constructivist theory explains how learners actively construct geometric knowledge through meaningful experiences, while sociocultural theory highlights the role of social interaction and cultural artefacts in mediating learning. Situated learning theory further argues that knowledge is most effectively acquired in authentic contexts that reflect real-life situations. Together, these theories provide a comprehensive framework for understanding how students reconstruct geometric concepts through culturally meaningful experiences while developing contextual problem-solving skills.

One pedagogical approach that aligns closely with this theoretical framework is ethnomathematics. Ethnomathematics integrates cultural practices, traditions, and local knowledge into mathematics instruction, enabling students to learn mathematics through contexts that are familiar within their sociocultural environments (Madimabe & Bayaga, 2026; Mania & Alam, 2021). This approach positions mathematics not merely as an abstract and universal discipline but as knowledge embedded within everyday human activities. Moreover, ethnomathematics promotes cultural identity and supports the development of more equitable and culturally responsive educational practices (Meixi et al., 2025; Rosa & Orey, 2021). By connecting mathematical concepts with students' lived experiences, ethnomathematics transforms abstract ideas into meaningful learning experiences and enhances conceptual understanding, numeracy, and problem-solving skills (Payadnya et al., 2024).

Within geometry education, ethnomathematics provides a meaningful approach for representing geometric concepts through local cultural artefacts such as traditional architecture, weaving patterns, ornaments, and community spatial practices. These cultural artefacts embody implicit mathematical structures that can be reconstructed into formal geometric concepts, enabling students to connect abstract geometry with authentic cultural experiences. Through engagement with culturally relevant contexts, students not only develop deeper conceptual understanding but also recognize the relevance of geometry in their daily lives and cultural environments. This perspective is consistent with the findings of Hohol and Miłkowski (2019), who emphasized that the historical development of geometry was closely linked to cognitive artefacts, cultural practices, and social interactions, as reflected in Euclid's achievements and other Greek geometric treatises. Such evidence suggests that mathematical knowledge is not developed in isolation but emerges through processes of enculturation and engagement with culturally embedded artefacts, reinforcing the importance of ethnomathematics as a bridge between cultural knowledge and formal geometry learning. In the Bimanese (Mbojo) cultural context relevant to this study, the Uma Lengge, a traditional conical-roofed granary used for communal rice storage, exemplifies such an artefact: its geometric structure embodies solid-geometry concepts, including cones, pyramids, and circular or square bases, that can be reconstructed into formal classroom learning of surface area and volume.

Several studies have reported that ethnomathematics-based instruction positively influences students' motivation, conceptual understanding, mathematical communication, and higher-order thinking

skills (Asare, 2026; Pratama & Yelken, 2024; Zuliana et al., 2025). However, most existing studies have focused primarily on the development of ethnomathematics-based learning materials, instructional media, or classroom implementation. Furthermore, no Design-Based Research (DBR) study has specifically investigated how geometric concepts can be reconstructed through an ethnomathematical perspective to enhance contextual problem-solving skills among junior secondary school students. Empirically, limited evidence is available regarding how ethnomathematics-based geometry learning develops students' contextual problem-solving skills. Theoretically, few studies have integrated constructivist, sociocultural, and situated learning perspectives to explain the process of geometric concept reconstruction, while methodologically the use of iterative Design-Based Research cycles remains underexplored.

This gap highlights the novelty of the present study, which integrates ethnomathematics, geometric concept reconstruction, and Design-Based Research within a single instructional framework. The novelty of this study lies in reconstructing formal geometric concepts from cultural contexts, integrating ethnomathematics and Design-Based Research through iterative instructional cycles, and examining their contribution to students' contextual problem-solving skills. To the best of the researchers' knowledge, no previous study has simultaneously integrated these aspects within junior secondary school geometry learning. Specifically, while prior ethnomathematics studies have demonstrated the pedagogical value of cultural contexts, they have rarely explained the mechanism by which informal cultural knowledge is reconstructed into formal geometric understanding, nor have they articulated the theoretical contribution of DBR-generated design principles to this reconstruction process. The present study addresses this gap by explicitly modelling the mechanism of conceptual reconstruction and by generating transferable design principles through the DBR cycle. Accordingly, the study was guided by the following three research questions:

RQ1: How can geometric concepts be reconstructed through an ethnomathematical perspective grounded in the Uma Lengge cultural artefact?

RQ2: How does this ethnomathematics-based geometric reconstruction influence students' contextual problem-solving skills?

RQ3: What characteristics of culturally grounded learning tasks support students' understanding during this reconstruction process?

Therefore, this study aims to reconstruct geometric concepts through an ethnomathematical perspective to improve students' contextual problem-solving skills among eighth-grade students at SMPN 1 Madapangga using a Design-Based Research approach.

## **METHODS**

This study employed a Design-Based Research (DBR) approach aimed at reconstructing geometric concepts through an ethnomathematical perspective to enhance students' contextual problem-solving skills. DBR was selected because it enables the iterative development, implementation, evaluation, and refinement of instructional designs in authentic educational settings while generating both practical and theoretical contributions (McKenney & Reeves, 2019).

The study was conducted at SMPN 1 Madapangga during the 2025/2026 academic year. The participants consisted of 30 eighth-grade students selected through purposive sampling. The sampling criteria included: (1) students had completed prior learning on basic plane geometry concepts according to the Grade VIII curriculum; (2) students were enrolled in a class where ethnomathematics-based geometry instruction could be implemented continuously throughout the study period; and (3) the class represented heterogeneous academic abilities based on mathematics achievement records provided by the school. These criteria were established to ensure that participants possessed sufficient prerequisite knowledge while allowing the instructional design to accommodate diverse learning needs. The selected class represented a typical Grade VIII classroom within the school and was chosen in consultation with the mathematics teacher and school administration to ensure the feasibility of implementing the initial instructional design in an authentic classroom setting. All participants voluntarily participated in the study,

and permission was obtained from the school authorities prior to data collection. The sample size was considered appropriate for the present Design-Based Research because the primary purpose of the study was to evaluate and refine an instructional design within an authentic classroom context rather than to achieve statistical generalisation. The use of one intact classroom enabled in-depth observation of students' learning processes and provided sufficient evidence to evaluate the practicality and effectiveness of the initial learning design.

This study adopted a Design-Based Research (DBR) approach consisting of four interconnected phases: preliminary analysis, design, implementation, and reflection (see Figure 1). During the preliminary analysis, students' learning difficulties in geometry and local cultural artefacts relevant to geometric concepts were identified through classroom observations, teacher interviews, and diagnostic assessments. The findings informed the development of an ethnomathematics-based learning design consisting of lesson plans, contextual worksheets, visual representations of cultural artefacts, and contextual problem-solving tasks.

This study implemented two Design-Based Research cycles. In Cycle 1, the initial ethnomathematics-based geometry learning design was implemented and evaluated in an authentic classroom setting; reflection on classroom observations, students' work, and interview findings identified aspects requiring refinement, which informed a set of design revisions (summarised in Table 6). These revisions were applied to produce a refined instructional design, which was subsequently implemented in Cycle 2 with the same 30 participants. Reflection following Cycle 2 indicated that no further substantive revisions were required, indicating that the instructional design had reached a mature and stable state suitable for broader implementation.

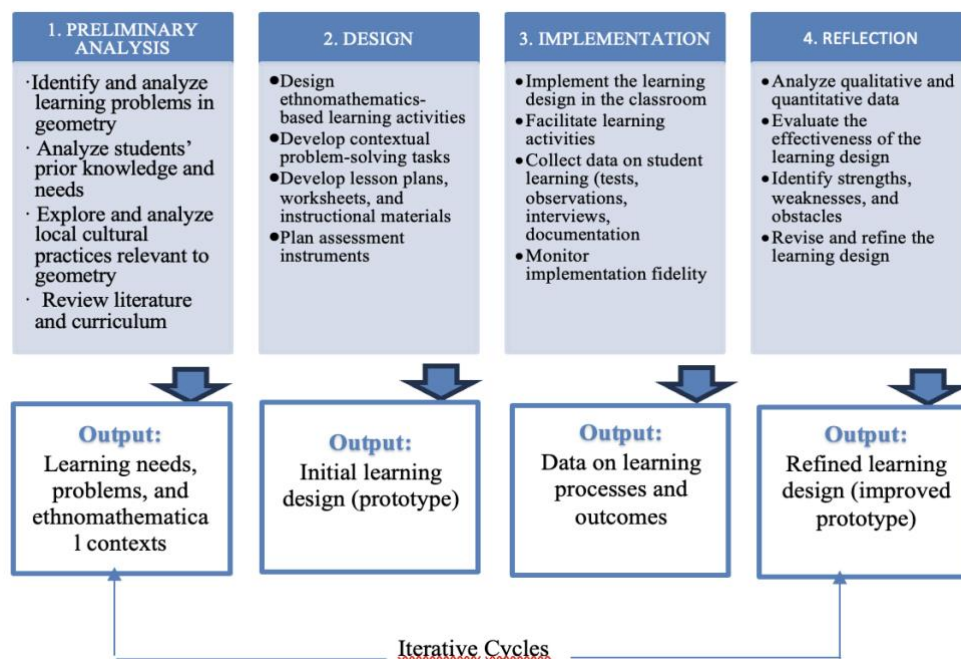


Figure 1. Design-Based Research Phases

Figure 1 illustrates the Design-Based Research framework adopted in this study. The process began with a preliminary analysis of students' geometry learning difficulties and relevant cultural contexts, followed by the development and implementation of the initial instructional design. Reflection was subsequently conducted using evidence gathered from classroom observations, students' learning outcomes, interviews, and documentation. The reflection findings informed recommendations for future refinement of the instructional design in subsequent iterations of the research.

The contextual problem-solving test was developed based on the OECD PISA mathematical literacy framework (OECD, 2023) and Polya's four stages of problem-solving: understanding the problem, devising a plan, carrying out the plan, and evaluating the solution. The test consisted of five open-ended geometry problems situated within local cultural contexts and was administered before and after the implementation of the learning intervention to measure changes in students' contextual problem-solving skills. Classroom observation sheets focused on student engagement, participation, collaborative interactions, and contextual reasoning processes. Semi-structured interview protocols were designed to explore students' conceptual understanding, learning experiences, perceptions of ethnomathematics-based geometry learning, difficulties encountered during learning, and suggestions for improving the instructional design. The interview guide consisted of six open-ended questions to ensure consistency across participants while allowing flexibility for further probing.

Prior to implementation, all instruments underwent expert validation involving three experts in mathematics education and ethnomathematics. The expert panel consisted of two mathematics education specialists and one ethnomathematics researcher with experience in curriculum development and mathematics learning assessment. Content validity was assessed using the Content Validity Ratio (CVR) and Content Validity Index (CVI), with CVR values ranging from 0.78 to 1.00 and an overall Scale-Level CVI (S-CVI) of 0.92, indicating excellent content validity. Instrument reliability was examined through a pilot study involving students with characteristics similar to the research participants, and the contextual problem-solving test demonstrated satisfactory internal consistency with a Cronbach's alpha coefficient of 0.87, indicating high reliability. Classroom observation sheets were used to record students' engagement, interaction, participation, and responses during the implementation of the learning activities. The scoring criteria were defined as follows: a score of 1 indicated very low participation, interaction, or conceptual engagement; 2 indicated low performance; 3 indicated moderate performance; 4 indicated high performance; and 5 indicated very high performance. The overall observation score for each student was calculated by averaging the scores across all observation indicators. The blueprints (kisi-kisi) of the contextual problem-solving test, classroom observation instrument, and semi-structured interview guide are presented in Tables 1-3 below to support the transparency and replicability of the research procedures; the full item wording is available from the corresponding author upon reasonable request.

Table 1. Blueprint of the Contextual Problem-Solving Test

| Indicator                             |              | Polya's Problem-Solving Stage | Item Number(s) | Number of Items |
|---------------------------------------|--------------|-------------------------------|----------------|-----------------|
| Understanding problems                | contextual   | Understanding the problem     | 1, 2           | 2               |
| Formulating models                    | mathematical | Devising a plan               | 3              | 1               |
| Applying geometric concepts           |              | Carrying out the plan         | 4              | 1               |
| Interpreting and evaluating solutions |              | Evaluating the solution       | 5              | 1               |
| Total                                 |              |                               |                | 5               |

Table 2. Blueprint of the Classroom Observation Instrument

| Indicator                      | Behavioural Descriptor (example)                                                       | Scoring Range |
|--------------------------------|----------------------------------------------------------------------------------------|---------------|
| Participation in discussion    | Frequency and quality of student contributions during whole-class and group discussion | 1–5           |
| Asking and answering questions | Frequency of student-initiated questions and accuracy of responses                     | 1–5           |
| Connecting concepts to context | Extent to which students relate geometric concepts to the Uma Lengge artefact          | 1–5           |
| Collaboration in group work    | Quality of peer interaction, task division, and mutual support                         | 1–5           |

Table 3. Blueprint of the Semi-Structured Interview Guide

| Aspect                                                                                    | Number of Questions |
|-------------------------------------------------------------------------------------------|---------------------|
| Conceptual understanding of geometric concepts reconstructed from the Uma Lengge artefact | 2                   |
| Learning experience during ethnomathematics-based instruction                             | 1                   |
| Perceptions of the ethnomathematics-based geometry learning design                        | 1                   |
| Difficulties encountered during learning                                                  | 1                   |
| Suggestions for improving the instructional design                                        | 1                   |
| Total                                                                                     | 6                   |

*Note.* The blueprints above summarise the constructs and item distribution of each instrument; the item/question distribution shown reflects the total item counts reported in the Methods section (five contextual problem-solving items; six interview questions) and should be verified by the authors against the original instrument documents prior to submission.

This study employed both quantitative and qualitative data analyses within the Design-Based Research (DBR) framework. Quantitative data were obtained from pre-test and post-test scores on contextual problem-solving tasks. The data were analysed using descriptive statistics, the Shapiro–Wilk normality test, paired-samples *t*-test, or the Wilcoxon signed-rank test when the assumption of normality was not satisfied. Statistical analyses were conducted using SPSS version 26 with a significance level of 0.05. In addition, normalized gain (N-gain) scores were calculated and interpreted based on Hake’s criteria to determine the magnitude of students’ learning improvement. To evaluate the practical significance of the intervention, Cohen’s *d* effect size and its corresponding 95% confidence interval were also calculated.

Qualitative data were collected through classroom observations, semi-structured interviews, and documentation. These data were analysed through data reduction, coding, categorisation, thematic interpretation, and triangulation. Data source triangulation and method triangulation were employed by comparing evidence obtained from tests, classroom observations, interviews, and documentation to enhance the credibility and trustworthiness of the findings. Finally, reflections on the implementation results were used to identify strengths, challenges, and aspects of the instructional design requiring further refinement in subsequent iterations of the Design-Based Research process.

## RESULTS & DISCUSSION

### Results

#### Preliminary Analysis Results

The preliminary analysis phase revealed that students experienced difficulties in connecting geometric concepts with real-life situations. To obtain empirical evidence regarding students’ initial understanding, a diagnostic test was administered before the learning intervention. Students’ performance was interpreted using percentage categories adapted from the school assessment criteria, namely: Very High (86–100%), High (71–85%), Moderate (56–70%), Low (41–55%), and Very Low ( $\leq 40\%$ ). These criteria were applied consistently to facilitate interpretation of the diagnostic findings. These five-band percentage categories follow a standard criterion-referenced classification scale commonly used in Indonesian school-based assessment, in which fixed percentage ranges (rather than researcher judgment) determine each category, thereby minimising subjectivity in the classification of students’ diagnostic scores.

Table 4. Diagnostic Assessment Results of Students’ Initial Geometry Understanding

| Indicator                           | Mean Score (%) | Category |
|-------------------------------------|----------------|----------|
| Understanding geometric concepts    | 60             | Moderate |
| Identifying geometric relationships | 57             | Moderate |

| Indicator                                               | Mean Score (%) | Category |
|---------------------------------------------------------|----------------|----------|
| Translating contextual situations into geometric models | 54             | Low      |
| Applying geometric concepts                             | 56             | Moderate |
| Interpreting solutions in real-life contexts            | 48             | Low      |
| Average Score                                           | 55             | Low      |

The diagnostic results indicate that students possessed procedural knowledge of geometry; however, their contextual and interpretative abilities were relatively weak. Students showed lower performance in contextual and interpretative aspects compared to procedural understanding, particularly in interpreting geometric solutions in real-life situations (48%). Following the development of ethnomathematics-based geometry learning activities, classroom observations revealed substantial improvements in student engagement and participation.

### Implementation Observation Results

During the implementation of the ethnomathematics-based learning design, classroom observations were conducted using a five-point observation rubric, where 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high participation. The observation focused on students' participation, questioning behaviour, contextual reasoning, and collaborative interaction. The mean scores presented in Table 2 represent the average observation scores obtained across all participants. All indicators in Table 2 were scored on the same 1-5 rubric described above (1 = very low, 5 = very high), so the reported means are directly comparable across indicators and time points.

Table 5. Observation of Student Engagement Before and After Implementation

| Indicator                      | Before Implementation<br>(Mean Score) | After Implementation<br>(Mean Score) |
|--------------------------------|---------------------------------------|--------------------------------------|
| Participation in discussion    | 2.1                                   | 4.3                                  |
| Asking and answering questions | 1.8                                   | 4.0                                  |
| Connecting concepts to context | 2.0                                   | 4.5                                  |
| Collaboration in group work    | 2.9                                   | 4.6                                  |

Students demonstrated increased engagement during learning activities, particularly in culturally based discussions, and showed improved ability to relate geometric concepts to real-life cultural contexts.

To evaluate the effectiveness of the ethnomathematics-based learning design, students completed contextual problem-solving tests before and after the intervention. Prior to conducting inferential analysis, a Shapiro–Wilk normality test was performed.

### Normality and Inferential Statistics

Table 6. Results of Normality Test, Paired-Samples t-Test, and Effect Size Analysis

| Analysis                | Statistic | df | p-value | Interpretation          |
|-------------------------|-----------|----|---------|-------------------------|
| Shapiro–Wilk (Pretest)  | W = 0.964 | 30 | 0.378   | Normally distributed    |
| Shapiro–Wilk (Posttest) | W = 0.972 | 30 | 0.592   | Normally distributed    |
| Paired-samples t-test   | t = 9.87  | 29 | < 0.001 | Significant improvement |
| Cohen's <i>d</i>        | 1.80      | -  | -       | Large effect size       |
| 95% Confidence Interval | 1.15–2.46 | -  | -       | Large positive effect   |

The Shapiro–Wilk test indicated that both pretest ( $W = 0.964$ ,  $p = .378$ ) and posttest ( $W = 0.972$ ,  $p = .592$ ) scores were normally distributed. Therefore, a paired-samples *t*-test was conducted. The analysis

revealed a statistically significant improvement in students' contextual problem-solving skills following the implementation of the ethnomathematics-based learning design,  $t(29) = 9.87$ ,  $p < .001$ . In addition, the intervention demonstrated a large practical effect, as indicated by Cohen's  $d = 1.80$  with a 95% confidence interval of 1.15–2.46, suggesting that the observed improvement was not only statistically significant but also educationally meaningful.

### Students' Contextual Problem-Solving Performance

Table 7. N-Gain Analysis of Contextual Problem-Solving Skills

| Indicator                             | Pretest (%) | Posttest (%) | N-Gain | Category |
|---------------------------------------|-------------|--------------|--------|----------|
| Understanding contextual problems     | 58          | 84           | 0.62   | Medium   |
| Formulating mathematical models       | 54          | 82           | 0.61   | Medium   |
| Applying geometric concepts           | 56          | 85           | 0.66   | Medium   |
| Interpreting and evaluating solutions | 52          | 80           | 0.58   | Medium   |
| Average Score                         | 55          | 83           | 0.62   | Medium   |

The average normalized gain score was 0.62, indicating a moderate improvement according to Hake's classification. When interpreted together with the large Cohen's  $d$  value (1.80), these findings suggest that the ethnomathematics-based learning design produced not only statistically significant learning gains but also substantial practical improvement in students' contextual problem-solving performance.

### Thematic Analysis of Student Interview Data

Interview transcripts were analysed through open coding, axial coding, and thematic categorisation. Two researchers independently coded the interview data before discussing discrepancies to achieve consensus. The intercoder agreement reached 91%, indicating high coding consistency. The analysis generated three major themes describing students' learning experiences during the implementation.

Table 8. Thematic Analysis of Student Interviews

| Theme                             | Code | Frequency   | Interpretation                                                                                                                                                                                                                                                                                      |
|-----------------------------------|------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Improved conceptual understanding | CU   | 18 students | "This finding indicates that students reconstructed formal geometric concepts by recognising mathematical structures embedded within familiar cultural artefacts. The reconstruction process enabled students to connect informal cultural experiences with formal geometric representations." (S7) |
| Increased learning relevance      | LR   | 21 students | "The lessons felt closer to our daily life because they used things from our community, Students consistently reported that geometry became easier to understand because mathematical ideas were presented through familiar cultural objects rather than abstract textbook illustrations." (S12)    |
| Enhanced engagement               | LE   | 25 students | "Group discussions became more active because we talked about familiar cultural examples, Classroom discussions encouraged collaborative reasoning, enabling students to compare multiple interpretations of cultural artefacts before                                                              |

| Theme | Code | Frequency | Interpretation                                             |
|-------|------|-----------|------------------------------------------------------------|
|       |      |           | agreeing upon appropriate geometric representations” (S18) |

The interview results show that students experienced improved conceptual understanding, increased relevance of learning, and higher engagement during ethnomathematics-based instruction.

Table 9. Reflection Findings and Design Revisions

| Reflection Findings                                                            | Design Revision                                          |
|--------------------------------------------------------------------------------|----------------------------------------------------------|
| Students had difficulty understanding worksheet instructions.                  | Instructions rewritten using simpler language.           |
| Students could not immediately identify geometric forms in cultural artefacts. | Additional guiding questions were incorporated.          |
| Several cultural images were unclear.                                          | Higher-quality photographs replaced the original images. |
| Discussion time was insufficient.                                              | Collaborative discussion time was extended.              |

Reflection on classroom observations, students’ work, and interview findings identified several aspects requiring refinement. Students initially experienced difficulty interpreting several contextual tasks because worksheet instructions were too general and some cultural illustrations lacked sufficient visual clarity. Based on these findings, the instructional design was revised by simplifying task instructions, incorporating guiding questions, improving visual representations of cultural artefacts, and extending collaborative discussion time. These revisions constitute the preliminary design principles generated through the first Design-Based Research cycle and provide recommendations for future implementation and refinement.

## Cycle 2 Implementation Results

Following the design revisions summarised in Table 9, the refined ethnomathematics-based geometry learning design was implemented in a second cycle with the same 30 eighth-grade participants. Data were collected using the same instruments as in Cycle 1 (classroom observation, contextual problem-solving tests, and semi-structured interviews) to evaluate whether the revised design produced further improvements and to determine whether the instructional design had reached a mature, stable state.

Table 10. Observation of Student Engagement Before and After Cycle 2 Implementation

| Indicator                      | Before Cycle 2 (Mean Score) | After Cycle 2 (Mean Score) |
|--------------------------------|-----------------------------|----------------------------|
| Participation in discussion    | 4.3                         | 4.8                        |
| Asking and answering questions | 4.0                         | 4.6                        |
| Connecting concepts to context | 4.5                         | 4.8                        |
| Collaboration in group work    | 4.6                         | 4.9                        |

Compared with the end of Cycle 1 (Table 5), student engagement continued to improve modestly across all four indicators during Cycle 2, with the largest remaining gains in asking and answering questions (4.0 to 4.6) and participation in discussion (4.3 to 4.8). The relatively small increments compared with the Cycle 1 gains suggest that engagement levels were approaching a ceiling by the end of Cycle 2.

Table 11. Results of Normality Test, Paired-Samples t-Test, and Effect Size Analysis (Cycle 2)

| Analysis                | Statistic | df | p-value | Interpretation       |
|-------------------------|-----------|----|---------|----------------------|
| Shapiro–Wilk (Pretest)  | W = 0.972 | 30 | 0.384   | Normally distributed |
| Shapiro–Wilk (Posttest) | W = 0.980 | 30 | 0.472   | Normally distributed |

| Analysis                | Statistic | df | p-value | Interpretation          |
|-------------------------|-----------|----|---------|-------------------------|
| Paired-samples t-test   | t = 9.76  | 29 | < 0.001 | Significant improvement |
| Cohen's d               | 1.75      | -  | -       | Large effect size       |
| 95% Confidence Interval | 1.15–2.30 | -  | -       | Large positive effect   |

As in Cycle 1, both pretest ( $W = 0.972$ ,  $p = .384$ ) and posttest ( $W = 0.980$ ,  $p = .472$ ) scores in Cycle 2 were normally distributed, justifying the use of a paired-samples t-test. The analysis again revealed a statistically significant improvement in students' contextual problem-solving skills,  $t(29) = 9.76$ ,  $p < .001$ , with a large effect size (Cohen's  $d = 1.75$ , 95% CI [1.15, 2.30]). The magnitude of the effect in Cycle 2 was comparable to that observed in Cycle 1 ( $d = 1.80$ ), indicating that the refined design sustained a similarly strong practical impact.

Table 12. N-Gain Analysis of Contextual Problem-Solving Skills (Cycle 2)

| Indicator                             | Pretest (%) | Posttest (%) | N-Gain | Category |
|---------------------------------------|-------------|--------------|--------|----------|
| Understanding contextual problems     | 84          | 87           | 0.19   | Low      |
| Formulating mathematical models       | 82          | 85           | 0.17   | Low      |
| Applying geometric concepts           | 85          | 88           | 0.20   | Low      |
| Interpreting and evaluating solutions | 80          | 83           | 0.15   | Low      |
| Average Score                         | 83          | 86           | 0.18   | Low      |

Unlike Cycle 1, which produced a moderate average N-gain (0.62) from a lower pretest baseline (55%), Cycle 2 began from a considerably higher baseline (83%, reflecting the cumulative gains already achieved in Cycle 1) and produced a comparatively small average N-gain of 0.18, falling into Hake's "low" category. This pattern is consistent with a ceiling effect: as students' scores approached the upper bound of the assessment scale, the mathematically available room for further normalized improvement narrowed considerably, even though absolute performance continued to rise (from 83% to 86% on average) and the effect size for the paired-samples comparison remained large (Table 11). Rather than indicating a failure of the refined design, the small N-gain alongside a large effect size and sustained high absolute scores suggests that the instructional design had approached the limits of improvement achievable within this assessment framework, supporting the judgement that the design had reached a mature, stable state.

Table 13. Thematic Analysis of Student Interviews (Cycle 2)

| Theme                             | Code | Frequency   | Interpretation                                                                                                                                                                                                                                                            |
|-----------------------------------|------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Improved conceptual understanding | CU   | 22 students | "Students increasingly demonstrated that they could identify and explain geometric concepts through familiar cultural artefacts. The reconstruction process helped them connect informal cultural knowledge with formal geometric representations more confidently." (S9) |
| Increased learning relevance      | LR   | 24 students | "The lessons felt meaningful because the examples came from our own community. Geometry became easier to understand when mathematical ideas were connected to objects and practices that we see in everyday life." (S14)                                                  |
| Enhanced engagement               | LE   | 25 students | "I was more interested in discussing the geometry because the examples were familiar to us. Group activities made us more active in comparing ideas, explaining our reasoning, and reaching agreement about the correct geometric representations." (S21)                 |

| Theme                               | Code | Frequency   | Interpretation                                                                                                                                                                                            |
|-------------------------------------|------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Strengthened mathematical reasoning | MR   | 23 students | “We did not only identify shapes; we had to explain why the cultural objects represented certain geometric concepts. This made us think more carefully, compare evidence, and justify our answers.” (S17) |

The three themes identified in Cycle 1 (improved conceptual understanding, increased learning relevance, and enhanced engagement) persisted into Cycle 2 with similar or slightly higher endorsement frequencies. Notably, a fourth theme, strengthened mathematical reasoning (MR, 23 students), emerged only in Cycle 2. Rather than merely identifying geometric forms within the Uma Lengge artefact, students in Cycle 2 more frequently described justifying why a cultural feature corresponded to a particular geometric property, comparing evidence, and constructing explanations. This shift suggests that the design revisions implemented after Cycle 1, particularly the addition of guiding questions, supported not only conceptual identification but also deeper mathematical justification, providing qualitative evidence that the design principles generated from Cycle 1 (see Discussion) functioned as intended when reapplied in Cycle 2.

Reflection conducted after Cycle 2, drawing on classroom observations, students' work, and interview data, did not identify any substantive instructional problems requiring further redesign. Task instructions, visual representations of the Uma Lengge artefact, and collaborative discussion time, each revised after Cycle 1, were judged by the researchers and the class teacher to be functioning effectively, with no recurring difficulties comparable in scale to those identified after Cycle 1 (Table 9). On this basis, the instructional design was judged to have reached a mature and stable state, and a third implementation cycle was not considered necessary within the scope of this study.

## Discussion

The findings of this study demonstrate that the reconstruction of geometric concepts through an ethnomathematical perspective effectively enhances students' contextual problem-solving skills and conceptual understanding of geometry. The improvement shown in Table 8 indicates that students experienced substantial progress across all indicators of contextual problem-solving, particularly in understanding contextual problems, formulating mathematical models, applying geometric concepts, and interpreting solutions. These findings suggest that embedding cultural contexts within geometry learning can make abstract mathematical concepts more concrete and meaningful for students. Ethnomathematics-based geometry lessons (using local motifs, crafts, buildings) improve students' conceptual understanding, critical thinking, collaboration, and motivation (Batiibwe, 2024; Motseki et al., 2026).

One important finding of this study is that students initially experienced difficulty in relating formal geometric concepts to contextual situations, as reflected in Table 1. This supports the argument that conventional geometry instruction often emphasizes procedural knowledge over conceptual understanding, causing students to rely heavily on formula memorization without fully comprehending geometric relationships. Conventional teaching in geometry is frequently characterized as teacher-centred and formula-oriented, with students focusing on reproducing procedures rather than constructing conceptual understanding (Gurmu et al., 2024; Owiti, 2023; Wardhani et al., 2023). Through ethnomathematics-based learning, students were encouraged to reconstruct geometric ideas from cultural contexts familiar to their everyday lives, enabling them to connect abstract concepts with authentic experiences.

The increased student engagement observed during implementation (Table 5) further indicates that culturally grounded learning tasks positively influence students' motivation and participation in mathematics learning. When students encountered geometry problems embedded in familiar cultural artifacts and practices, they became more actively involved in discussion, collaborative reasoning, and exploration of multiple solution strategies. This finding aligns with constructivist learning theory, which emphasizes that meaningful learning occurs when students actively construct knowledge through relevant experiences. Consistent with this view, studies on spatial skills in geometry learning have demonstrated

the value of constructivist approaches in enhancing students' understanding of geometric concepts (Owiti, 2023; Wardhani et al., 2023).

The statistically significant improvement between pretest and posttest scores ( $t(29) = 9.87, p < .001$ ) confirms the effectiveness of the ethnomathematics-based learning intervention in enhancing students' contextual problem-solving skills. The N-gain results indicate that the highest improvement occurred in applying geometric concepts (0.66), while interpreting and evaluating solutions showed the lowest gain (0.58), suggesting that higher-order reasoning skills require longer instructional support. By analyzing geometric structures embedded in cultural artifacts, students were able to identify mathematical patterns, represent them symbolically, and apply appropriate geometric reasoning. This process reflects successful conceptual reconstruction, where students transform intuitive contextual understanding into formal mathematical knowledge. These findings are consistent with Jainuddin and Herman (2025), who reported improved conceptual understanding and spatial reasoning; Lazarinis (2025), who found increased motivation and critical thinking; and Tessema et al. (2024), who emphasized learning from concrete experiences toward abstract mathematical concepts.

The results also corroborate the findings of Boonstra et al. (2023), who described that teachers often rely on textbooks whose tasks are not designed to support the use of manipulatives or realistic geometry contexts. As a result, abstraction is frequently pursued without a concrete foundation, and teachers may encounter difficulties in guiding students' geometric reasoning. Before the intervention, students in the present study exhibited similar challenges in relating geometric concepts to contextual problems. Moreover, the observed improvement in contextual problem-solving skills aligns with the systematic review conducted by Andang et al. (2026), which concluded that digital ethnomathematics-based geometry materials significantly improved students' problem-solving abilities compared with conventional instructional resources and explicitly attributed these gains to culturally grounded learning tasks. Consistent with the findings of Asare (2026), the results of the present study underscore the transformative potential of embedding cultural contexts in mathematics instruction to enhance student engagement, learning relevance, and academic outcomes. These findings provide compelling evidence for curriculum reform toward more inclusive and culturally responsive mathematics education.

Furthermore, interview findings revealed that students perceived geometry as easier to understand when learning activities were linked to local cultural contexts. This indicates that ethnomathematics not only improves cognitive learning outcomes but also enhances students' perceptions of mathematics as relevant and meaningful. Such findings reinforce the idea that culturally responsive pedagogy can help reduce students' anxiety toward abstract mathematical topics and foster more positive learning attitudes. Tasks designed around cultural artifacts guide students from informal, culturally grounded insights to formal definitions, rules, and proofs in geometry (Sari et al., 2025).

The present findings are also consistent with a broader body of research in ethnomathematics and culturally responsive mathematics education. For instance, Payadnya et al. (2025) argued that when mathematics instruction is connected to students' lived experiences, including local crafts, architecture, music, and language, learning becomes more concrete, contextual, and meaningful. Similarly, Zuliana et al. (2023) demonstrated that traditional Javanese mosque architecture embodies geometric concepts such as cuboids, cylinders, symmetry, and geometric transformations that can support contextualised geometry learning. The findings of the present study are also consistent with those of Fernández-Oliveras et al. (2021), who emphasized that mathematical understanding can be developed through cultural activities and traditional practices that provide meaningful contexts for learning. Several scholars have further described mathematics as a cultural product that emerges from human activities and sociocultural practices. The current findings extend this body of research by demonstrating that the reconstruction of geometric concepts through local cultural contexts not only improves conceptual understanding but also strengthens students' contextual problem-solving skills within a Design-Based Research framework.

The iterative refinement process conducted throughout the design-based research cycles also contributed significantly to the effectiveness of the learning design. As shown in Table 4, revisions involving simplified task instructions, improved contextual visualization, and structured discussion prompts enhanced the accessibility and clarity of the instructional materials. This demonstrates that

iterative reflection and redesign are essential for optimizing culturally contextualised learning interventions. Ethnomathematics textbooks and teaching resources often undergo internal review, expert validation, readability testing, and multiple cycles of revision informed by stakeholder feedback to ensure that the final products are both practical and pedagogically effective (Hortelano & Lapinid, 2024; Marsigit et al., 2026).

### **Design Principles Generated from DBR**

Synthesising the reflection findings summarised in Table 9, this study generated four preliminary design principles for ethnomathematics-based geometry instruction using the Uma Lengge artefact: (1) worksheet instructions should be phrased in simple, concrete language rather than formal mathematical register, since students initially struggled to interpret general task wording; (2) guiding questions should be embedded directly alongside cultural images to scaffold students' identification of geometric forms within unfamiliar cultural artefacts; (3) visual representations of cultural artefacts must be high-resolution and unambiguous, as unclear imagery impeded students' ability to map informal cultural features onto formal geometric structures; and (4) collaborative discussion time should be extended beyond initial estimates to allow students to negotiate multiple interpretations of the same artefact before converging on a shared geometric representation. Mechanistically, these principles suggest that conceptual reconstruction proceeded through a three-step process observable in the interview data: students first recognised a familiar cultural form (e.g., the conical roof of the Uma Lengge), then, prompted by guiding questions and peer discussion, re-described that form using geometric vocabulary (cone, base, height), and finally applied that vocabulary to solve a contextual problem. This sequence constitutes the study's transferable design-knowledge contribution. These principles were subsequently re-applied in Cycle 2 (see Cycle 2 Implementation Results), where sustained large effect sizes, continued gains in engagement, and the emergence of a fourth interview theme strengthened mathematical reasoning and provided empirical confirmation that the design principles generated from Cycle 1 functioned as intended.

The findings of this study are also consistent with previous Design-Based Research (DBR) studies that have integrated ethnomathematical perspectives into mathematics learning. For example, Hunter and Miller (2020) demonstrated that iterative design cycles enabled the refinement of culturally meaningful learning activities that improved students' mathematical reasoning and conceptual understanding. Similarly, McKenney and Reeves (2019) argued that DBR is particularly effective for developing context-sensitive instructional interventions because continuous reflection and redesign allow learning materials to be progressively aligned with students' needs and cultural backgrounds. In the context of ethnomathematics, Rosa and Orey (2023) reported that culturally grounded mathematical tasks facilitated students' ability to connect informal cultural knowledge with formal mathematical concepts, resulting in deeper conceptual understanding and increased engagement. Likewise, Aikenhead (2017) found that integrating local cultural practices into mathematics instruction promoted meaningful learning experiences and strengthened students' problem-solving abilities. Furthermore, Batiibwe (2024) demonstrated that contextualised and technology-supported geometry learning can enhance students' conceptual understanding and spatial reasoning by providing meaningful representations of geometric concepts. Consistent with these studies, the present research demonstrates that the iterative reconstruction of geometric concepts through an ethnomathematical perspective not only improves students' contextual problem-solving skills but also contributes to the refinement of instructional design through successive cycles of implementation, evaluation, and reflection. Therefore, the contribution of this study extends beyond demonstrating the effectiveness of ethnomathematics-based learning by providing an empirically validated DBR framework for reconstructing geometric concepts in junior secondary education.

Taken together, the quantitative improvements observed in students' contextual problem-solving performance, the qualitative evidence from interviews and classroom observations, and the iterative refinement of the instructional design indicate that ethnomathematics-based geometry learning constitutes an effective and theoretically grounded pedagogical approach. Drawing on constructivist, sociocultural, and situated learning perspectives, the findings suggest that cultural contexts function as meaningful

mediational tools that support students in reconstructing abstract geometric concepts. Moreover, in line with previous DBR studies in mathematics education, the iterative design process proved essential for optimizing learning activities and ensuring their relevance to students' cultural experiences. Consequently, this study contributes both a practical instructional model and empirical evidence supporting the integration of ethnomathematics and Design-Based Research to enhance contextual problem-solving skills in secondary geometry education.

## CONCLUSION

This study set out to examine how the reconstruction of geometric concepts through an ethnomathematical perspective, developed via a two-cycle Design-Based Research process, affects students' contextual problem-solving skills, and the findings provide a clear answer: grounding geometry instruction in the local cultural artefact of Uma Lengge was associated with a statistically significant improvement in students' contextual problem-solving performance, evidenced by large and consistent effect sizes across both cycles (Cohen's  $d = 1.80$  and  $1.75$ ) and a moderate average N-gain, alongside deeper mathematical reasoning, greater engagement, and stronger learning relevance observed in the second cycle. These results indicate that connecting abstract geometric concepts to authentic cultural experiences supports more meaningful conceptual reconstruction and more effective problem-solving processes, while the iterative DBR cycles allowed the instructional design to be refined into a stable, classroom-ready form. Given the absence of a control group and the single-class, single-teacher setting, these conclusions should be read as evidence of practical association rather than strict causal proof, since maturation, practice, Hawthorne, and teacher effects cannot be fully ruled out. Nonetheless, the consistency of outcomes across cycles supports ethnomathematics-based reconstruction as a viable, culturally responsive strategy for improving geometry learning at the secondary level. In operational terms, teachers and curriculum developers are encouraged to adopt locally meaningful cultural artefacts as entry points for reconstructing geometric concepts, and schools in similarly rich cultural settings may adapt this DBR-based design to their own contexts. Future work should extend this approach with larger and more diverse samples, comparison groups, longer implementation periods, other mathematical domains such as algebra and statistics, and the integration of digital or interactive media, in order to strengthen the generalizability and long-term impact of ethnomathematics-based instruction.

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