

ORIGINAL

Designing RME-based learning trajectory with the context of ethnomathematics of Rumah Gadang Minangkabau using augmented reality

Diseño de la trayectoria de aprendizaje basada en RME con el contexto de las etnomatemáticas de Rumah Gadang Minangkabau utilizando la realidad aumentada

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ABSTRACT

Introduction: the integration of cultural context and educational technology is essential to enhance students' engagement and understanding in mathematics. This study aims to design and implement a Realistic Mathematics Education (RME)-based Hypothetical Learning Trajectory (HLT) supported by Augmented Reality (AR), using ethnomathematics in *Rumah Gadang* (Big House) as a contextual foundation.

Method: this study used a mixed-method approach combining ethnography and design research. An ethnographic exploration of *Rumah Gadang* (Big House) in West Sumatra identified mathematical ideas embedded in its architecture. These findings informed the design of a Realistic Mathematics Education (RME)-based Hypothetical Learning Trajectory (HLT), enhanced with Augmented Reality (AR). The HLT underwent formative evaluation through expert review and one-to-one evaluation. Data were analyzed qualitatively and quantitatively to assess validity and practicality.

Results: the RME-based HLT enabled students to construct mathematical understanding progressively through familiar cultural contexts, such as *Rumah Gadang* (Big House) staircases and traditional ornaments. The integration of AR significantly increased student engagement, facilitated the visualization of abstract concepts, and supported collaborative learning. Teachers reported improved lesson planning and student participation, while students demonstrated enhanced mathematical reasoning and motivation.

Conclusions: designing HLT using RME principles and delivering it through AR creates a powerful synergy that connects abstract mathematical concepts with students' real-world experiences. This approach not only improves cognitive outcomes but also strengthens students' cultural identity and appreciation. The study suggests that the combination of pedagogy, culture, and technology can transform mathematics education into a more meaningful, inclusive, and engaging experience.

Keywords: Augmented Reality in Mathematics; Ethnomathematics; Hypothetical Learning Trajectory; Realistic Mathematics Education.

RESUMEN

Introducción: la integración del contexto cultural y la tecnología educativa es esencial para mejorar la participación y la comprensión de los estudiantes en matemáticas. Este estudio tiene como objetivo diseñar e implementar una Trayectoria de Aprendizaje Hipotética basada en la Educación Matemática Realista respaldada por la Realidad Aumentada, utilizando las etnomatemáticas en *Rumah Gadang* (Casa Grande) como base contextual.

Método: este estudio utilizó un enfoque de método mixto que combina etnografía e investigación de diseño. La exploración etnográfica de *Rumah Gadang* (Casa Grande) en Sumatra Occidental identificó ideas matemáticas incrustadas en su arquitectura. Estos hallazgos informaron el diseño de una Trayectoria de Aprendizaje Hipotética basada en la Educación Matemática Realista, mejorada con Realidad Aumentada. El Trayectoria de Aprendizaje Hipotética se sometió a una evaluación formativa a través de la revisión de expertos y la evaluación individual. Los datos se analizaron cualitativamente y cuantitativamente para evaluar la validez y la practicidad.

Resultados: la Trayectoria de Aprendizaje Hipotética basada en Educación Matemática Realista permitió a los estudiantes construir una comprensión matemática progresivamente a través de contextos culturales familiares, como *las escaleras de Rumah Gadang* (Casa Grande) y los adornos tradicionales. La integración de Realidad Aumentada aumentó significativamente la participación de los estudiantes, facilitó la visualización de conceptos abstractos y apoyó el aprendizaje colaborativo. Los maestros informaron una mejor planificación de lecciones y participación de los estudiantes, mientras que los estudiantes demostraron un mejor razonamiento matemático y motivación.

Conclusiones: diseñar Trayectoria de Aprendizaje Hipotética utilizando los principios de Educación Matemática Realista y entregarla a través de Realidad Aumentada crea una poderosa sinergia que conecta conceptos matemáticos abstractos con las experiencias del mundo real de los estudiantes. Este enfoque no solo mejora los resultados cognitivos, sino que también fortalece la identidad cultural y el aprecio de los estudiantes. El estudio sugiere que la combinación de pedagogía, cultura y tecnología puede transformar la educación matemática en una experiencia más significativa, inclusiva y atractiva.

Palabras clave: Realidad Aumentada en Matemáticas; Etnomatemáticas; Trayectoria de Aprendizaje Hipotética; Educación Matemática Realista.

INTRODUCTION

The persistent underperformance of Indonesian students in mathematics, evidenced by international assessments, has long been a matter of national concern. In the 2018 Programme for International Student Assessment (PISA), Indonesia's average mathematics score was 379, significantly below the Organisation for Economic Co-operation and Development (OECD) mean of 489, placing the country at 73rd out of 79 participating nations.^(1,2) The Trends in International Mathematics and Science Study (TIMSS) has revealed similar results, with Indonesian students consistently performing below the international average in both content knowledge and application-based tasks.^(2,3,4) More strikingly, detailed analyses indicate that Indonesian students struggle most with contextual and application-oriented problems, precisely the type of competencies emphasized in 21st-century education.^(5,6,7,8) Scholars have argued that this performance gap is rooted not only in the dominance of conventional, teacher-centred approaches that emphasize mechanical procedures but also in the lack of meaningful connections between mathematics instruction and students' everyday realities.^(9,10,11) Consequently, there is an urgent need for innovative pedagogical approaches that can bridge the gap between abstract mathematical concepts and students' lived experiences, thereby fostering both cognitive development and problem-solving capacity.

Realistic Mathematics Education (RME) represents one such approach that has gained global recognition for its effectiveness. Developed in the Netherlands, RME emphasizes guided reinvention, starting from realistic contexts that are meaningful to learners and supporting their gradual progression toward formal mathematics.^(12,13,14,15,16,17,18,19,20,21) In the Indonesian context, RME has been adopted and localized under *Pendidikan Matematika Realistik Indonesia* (PMRI), with numerous studies demonstrating improvements in student understanding, motivation, and engagement.^(14,19,22,23,24,25) Importantly, RME aligns with the curriculum emphasis on contextual, student-centred learning that values local culture and diversity.^(26,27,28,29) A closely related framework is the Hypothetical Learning Trajectory (HLT), a design tool that comprises three key elements: learning goals, carefully structured activities, and hypotheses about students' learning processes.^(30,31,32,33) By anticipating how students might approach tasks, HLT enables teachers to support the reinvention process coherently and adaptively. Empirical studies have shown that HLT grounded in RME principles can lead to advanced calculus.⁽³⁴⁾

The literature also points to the central role of problem solving and problem posing in fostering deep mathematical understanding. Rott et al.⁽³⁵⁾ emphasized that conceptualizing problem solving as an iterative cycle of exploration, structuring, and reflection aligns closely with the phased nature of RME-based HLT.⁽³⁵⁾ Similarly, Papadopoulos et al.⁽³⁶⁾ argue that problem posing not only nurtures creativity but also enhances students' agency by enabling them to mathematize everyday phenomena in personally meaningful ways.⁽³⁶⁾ Embedding these practices into the design of HLT ensures that learners do not passively receive knowledge but actively construct and extend it, which is vital for developing higher-order thinking skills demanded in international benchmarks like PISA.

At the same time, scholars have highlighted the importance of cultural relevance in mathematics instruction. The field of ethnomathematics has shown that cultural practices and artifacts offer powerful entry points for making mathematics meaningful and accessible.^(37,38,39) In Indonesia, many examples range from traditional measurement methods in agriculture to architectural styles in local houses. The *Rumah Gadang* (Big House) of West Sumatra, for example, features complex geometric, proportional, and transformational designs in its structure and decoration.^(26,40,41) Empirical studies demonstrate that when such ethnomathematical contexts are incorporated into instruction, students show increased motivation, improved conceptual understanding, and stronger cultural identity.^(42,43,44,45,46,47,48) Integrating these cultural dimensions into RME-based HLT thus holds potential for addressing both the cognitive and affective domains of learning, ensuring that mathematics is perceived not as a foreign subject but as a natural extension of students' cultural experiences.

Technological innovation provides further opportunities for strengthening this integration. Augmented Reality (AR), which overlays computer-generated content onto real environments, has increasingly been explored in mathematics education as a tool for enhancing visualization and interaction.^(45,46,47,48) Research suggests that AR can foster spatial reasoning, conceptual understanding, and engagement by allowing students to manipulate three-dimensional representations of abstract objects.^(49,50,51,52,53) In the Indonesian context, AR has been shown to reduce mathematics anxiety and encourage active participation, particularly in the implementation of the curriculum.⁽⁵⁴⁾ For instance, learners can rotate, reflect, and scale three-dimensional objects when exploring *Rumah Gadang* (Big House) ornaments using augmented reality (AR), which makes ideas like symmetry and metamorphosis more concrete than they would be with standard two-dimensional textbook depictions. However, despite this promise, many implementations of AR in education have remained limited, functioning more as technological add-ons rather than as integrated components of pedagogically grounded instructional designs.^(55,56,57) For example, AR applications can enable students to manipulate three-dimensional models of cultural artifacts such as *Rumah Gadang* (Big House) ornaments, making concepts like rotation and reflection more accessible.



Figure 1. Example of an AR interface displaying a 3D model for geometric exploration

Although RME, ethnomathematics, and AR have each demonstrated substantial contributions to mathematics education, the literature shows that these strands have largely evolved in isolation. RME-based studies emphasize context and reinvention but often lack the technological affordances to enhance visualization.^(58,59,60) Ethnomathematics research reveals the richness of cultural contexts but is sometimes criticized for superficial treatment without systematic scaffolding.^(39,61,62,63) AR applications in mathematics classrooms have yielded encouraging results for engagement and visualization, but often operate independently of robust pedagogical frameworks.^(52,64) Few studies have attempted to systematically integrate all three RME principles, ethnomathematical contexts, and AR technology into the design, validation, and implementation of comprehensive HLT. This lack of integration constitutes a critical gap in the literature, particularly in Indonesia, where innovative approaches are needed to meet curricular demands while respecting cultural diversity and preparing students for participation in a digital society.

The present study seeks to address this gap by designing, developing, and evaluating Hypothetical Learning Trajectories that are grounded in RME principles, enriched with Indonesian ethnomathematics, and supported by Augmented Reality. The research explores mathematical concepts embedded in *Rumah Gadang* (Big House) as authentic contexts for instruction, translates these contexts into progressive learning trajectories, develops

AR applications that allow students to interact with cultural artifacts in new ways, and examines how this integrated model can be implemented in classrooms. This work advances local instructional theory and shows how abstract mathematics can be genuinely located in cultural contexts while keeping formal rigor by bringing pedagogy, culture, and technology together. In addition, it advances practice by providing creative teaching methods that complement the curriculum, encourage cultural awareness, and give students the tools they need to succeed in a technologically advanced future. The study's ultimate goal is to make mathematics instruction in Indonesia a more purposeful, interesting, and fair undertaking that fosters local identity while improving performance internationally.

METHOD

This study employed a mixed methodological approach that combined ethnography and design research. ^(14,21,65,66) This methodological integration was chosen due to the dual objectives of the study: first, to explore and document the ethnomathematical practices inherent in the *Rumah Gadang* (Big House) as a cultural artifact of the Minangkabau people, and second, to design, validate, and evaluate a pedagogical model in the form of an RME-based HLT supported by AR. Ethnography provided in-depth and contextual insights into mathematical reasoning embedded in cultural practices. ^(37,39) Design research offered a systematic and iterative framework for developing, testing, and refining instructional innovations. ^(65,67) The combination of both approaches ensured that the resulting instructional design was culturally authentic and pedagogically robust.

Ethnographic Study

The ethnographic phase was conducted in a selected *Rumah Gadang* (Big House) located in West Sumatra, Indonesia. Data were collected through participant observation and semi-structured interviews with a *tukang tuo* (master carpenter) who possesses traditional architectural knowledge transmitted across generations. Observations focused on architectural elements such as the *gonjong* (roof ends), carved ornaments, staircases, walls, and floor patterns. Interviews explored construction reasoning related to proportion, symmetry, and measurement systems. The ethnographic data were analyzed thematically based on Bishop's six ethnomathematical domains: counting, measuring, locating, designing, playing, and explaining. The findings revealed rich mathematical ideas in the *Rumah Gadang* (Big House), including proportional reasoning, symmetry, and geometric transformations that could be integrated into school mathematics.

Design Research Phases

Following the ethnographic exploration, the design research process was carried out following the framework proposed by Plomp and Nieveen, ⁽⁶⁶⁾ which consists of three major phases: preliminary research, prototyping, and assessment. ^(65,66,68)

Preliminary Research Phase

This phase aimed to build a foundation for design through various analyses:

- Ethnomathematical analysis, identifying mathematical concepts from *Rumah Gadang* (Big House) architecture that are suitable for integration into mathematics learning. ^(39,69)
- Curriculum analysis, aligning these cultural contexts with the Indonesian curriculum, particularly in geometry topics. ⁽⁷⁰⁾
- Concept analysis involves mapping the connections between formal mathematical ideas and identifiable ethnomathematical aspects (such as symmetry, proportion, and transformation).
- Student characteristics analysis, identifying prior knowledge, learning needs, and common misconceptions of Grade VII students. ⁽⁷¹⁾

The triangulation of these analyses ensured that the designed learning trajectory was relevant to both students' cultural experiences and curricular goals.

Prototyping Phase

In this phase, the researchers designed the RME-based Hypothetical Learning Trajectory, integrating ethnomathematical contexts and AR technology. The HLT consisted of three key components as conceptualized by Simon ⁽³³⁾: learning goals, sequences of instructional activities, and hypotheses of students' learning processes.

To ensure quality, formative evaluations were conducted following Tessmer's framework: ^(72,73)

- Self-evaluation, conducted by the research team to check internal coherence and feasibility.
- Expert review, involving five experts in mathematics education, educational technology, and linguistics, to assess mathematical accuracy, AR integration, and linguistic clarity. ⁽⁷⁴⁾
- One-on-one evaluation, conducted with three Grade VII students (high, medium, and low ability) to test the clarity, practicality, and AR-supported worksheets.

Feedback from experts led to revisions in terminology simplification, scaffolding reinforcement, and visual enhancement. Student observations and interviews provided insights into engagement, strategy use, and the comprehensibility of AR-based materials.

Assessment Phase

The assessment phase examined the impact of the validated HLT on students' mathematical understanding and engagement when learning geometry with AR support. This phase focused on identifying how the RME-based learning trajectory helped students connect cultural contexts with formal mathematics concepts. Data included students' task performance, engagement levels during AR-based exploration, and qualitative feedback from observations and interviews.⁽⁷⁵⁾

Data Analysis

Data were analyzed using a mixed-method approach. Qualitative data from interviews, observations, and open responses were analyzed thematically to identify patterns of reasoning, engagement, and cultural appreciation.⁽⁷¹⁾ Quantitative data from expert validation sheets and worksheet completion scores were analyzed descriptively to evaluate the validity and practicality of the HLT design. Triangulation of data sources enhanced the reliability and credibility of findings.⁽⁷⁶⁾ Given the limitation of space, this article reports results from four key aspects: the ethnographic findings, the designed HLT model, expert validation outcomes, and results from one-to-one and worksheet assessments. Together, these findings demonstrate the feasibility of integrating cultural contexts, RME design principles, and AR technology to develop a culturally grounded and pedagogically effective instructional model for mathematics learning.

RESULTS

Ethnomathematical Exploration Results

The first phase of the study focused on the ethnomathematical exploration of the *Rumah Gadang* (Big House), a cultural representation of the Minangkabau community. This exploration aimed to identify the mathematical concepts embedded in architectural elements and ornaments as potential contexts for geometry learning. Researchers conducted systematic observations and measurements of structural parts such as the *gonjong* (roof ends), pillars, slanted wall boards, windows, doors, carved ornaments, stairs, and space dividers. Each element was documented through sketches, photographs, and measurement records to reveal its mathematical relevance.

The findings demonstrated the presence of concepts such as lines, angles, plane figures, circles, and geometric transformations. These results demonstrate how Minangkabau architecture naturally incorporates mathematical reasoning within cultural practices. The ethnomathematical data were then organized into six basic mathematical activities. Counting, measuring, locating, designing, playing, and explaining based on the theoretical framework proposed by Bishop.



Figure 2. Example of a *Rumah Gadang* (Big House) ornaments with transformation geometry concepts

This image exemplifies how proportionality, symmetry, and rotation appear in Minangkabau carving and serves as one entry point for contextualizing geometry learning.

This categorization highlights the sophistication of indigenous knowledge systems and their potential to serve as authentic contexts for mathematics instruction.

Math Activities	Manifestations in <i>Rumah Gadang</i> (Big House)	Mathematical Concepts
Counting	- The sum of spaces is always odd (3,5,7)	- Odd numbers
Measuring	- <i>Hasta</i> (ell) and <i>depa</i> (fathom)	- System of measurement
	- Ladders follow the Pythagorean principle	- Pythagorean Theorem
Locating	- North-south orientation	- Cartesian coordinates
	- Hierarchical-based spatial planning	- Geometric transformation
Designing	- Symmetrical of the <i>gonjong</i> (roof ends)	- Reflection symmetry
	- 8/12 faceted prism-shaped poles	- Polygons
	- Fractal engraving	- Geometric transformations
Playing	- Odd number wall bamboo	- Mathematical logic
	- Specific angle between beams	- Angular geometry
Explaining	- Description of pole vector	- Vector
	- Analogue of a roof parabolic	- Square function

This table integrates field findings from research with cutting-edge ethnomathematical theory, highlighting the depth of mathematical thinking in Minangkabau culture that is often overlooked in formal curricula. The natural integration of mathematics in cultural practices makes them ideal foundations for RME-based learning trajectories, as they provide authentic, meaningful contexts that resonate with students' cultural identities.

Integration of Ethnomathematical, Curricular, and Student Analyses into HLT and AR Design

Based on the results of the ethnomathematical exploration, the research team conducted complementary analyses of the curriculum, mathematical concepts, and student characteristics to ensure that the designed instruction would be pedagogically and contextually aligned. Due to the curriculum's strong emphasis on contextualized, student-centered learning, triangles, quadrilaterals, and transformations were mapped to geometric concepts found in *Rumah Gadang* (Big House), such as symmetry in roof structures, proportional relationships in staircases, and transformations in ornaments.

Curriculum analysis ensured that these cultural contexts supported official learning outcomes, while concept analysis clarified the relationships between ethnomathematical observations and formal mathematical ideas. The analysis of student characteristics, particularly those of Grade VII students, informed the sequencing of learning activities and the level of scaffolding required. From these integrated analyses, an RME-based HLT was designed, structured into six progressive phases: orientation and perception, field exploration, data representation, processing and calculation, discussion and abstraction, and application and reflection. Additionally, AR media were developed to visualize three-dimensional elements of *Rumah Gadang* (Big House), allowing students to explore geometric transformations, proportions, and symmetries interactively. The integration of AR was intended to enhance engagement, spatial reasoning, and conceptual understanding.

Phase	Learning Goals	Learning Activities	Student Strategy Prediction	Anticipating Misconceptions & Teacher Intervention	Expected Learning Outcomes
1. Orientation & Perception	Students recognize the context of the <i>Rumah Gadang</i> (Big House) and relate it to the concept of a flat building.	The teacher displays a picture of a house, provoking the question: "What shape do you see on the roof, walls, stairs, and ornaments?"	Some students call common shapes such as triangles, rectangles, and circles. Others have not been able to associate the shape with part of the <i>Rumah Gadang</i> (Big House).	If students only mention shapes for no reason, the teacher guides with guiding questions such as "Which part is triangular?"	Students can name at least 3 geometric shapes in the <i>Rumah Gadang</i> (Big House) and their locations.
2. Field Exploration / Media	Students can identify and measure dimensions of the part of <i>Rumah Gadang</i> (Big House).	Students (through pictures or visits) fill out the worksheet: measure length, width, height, and angle. Sketch Simple.	Students use measuring tools appropriately. Recording the results in the worksheet table, some only guess the size.	The teacher reminded him how to use a ruler and showed an example of measurement.	Students generate accurate measurement data on the worksheet.

3. Representation	Students organize measurement data into tables and sketches.	Populate worksheet columns with drawings, size tables, and geometric shape labels.	Some students draw with the right proportions; some don't.	The teacher shows an example of a proportional sketch.	The worksheet contains clear tables & drawings with the correct size and shape.
4. Processing & Calculation	Students calculate the circumference and area of the shapes found.	Using the circumference/area formula on the shape of the identification result (triangle, rectangle, parallelogram, or circle).	Students remember the formula from memorization, but there is a mistake in substituting the value.	The teacher reminded the formula with simple examples and emphasized the unit of measure.	Students can calculate the circumference/area correctly and include units.
5. Discussion & Abstraction of Concepts	Students deduce the properties of a flat building based on observations.	Group presentation, comparing measurement results, deducing properties.	Students can mention the properties of triangles, rectangles, and parallelograms; some are wrong in the definition of an angle.	The teacher straightens definitions with visual examples.	Students understand the properties of flat buildings according to formal mathematics concepts.
6. Application & Reflection	Students apply concepts to new problems.	Work on advanced contextual problems in the worksheet, for example, calculating the length of the roof of the <i>Rumah Gadang</i> (Big House) or the area of the wall board.	Students try out their calculation strategies, some using a visual approach.	Teachers give positive feedback and alternative solutions.	Students can solve new problems with the correct concepts.

Validation Results

The HLT validation process involved five experts representing three academic domains: mathematics education, educational technology, and linguistics. Cross-disciplinary evaluation was essential to ensure conceptual accuracy, effective integration of cultural elements, appropriate technological support, and linguistic clarity. Experts assessed the completeness of the HLT structure, the relevance of activities inspired by the *Rumah Gadang* (Big House) ethnomathematics, and the clarity of the language used in the worksheets and teacher guides.

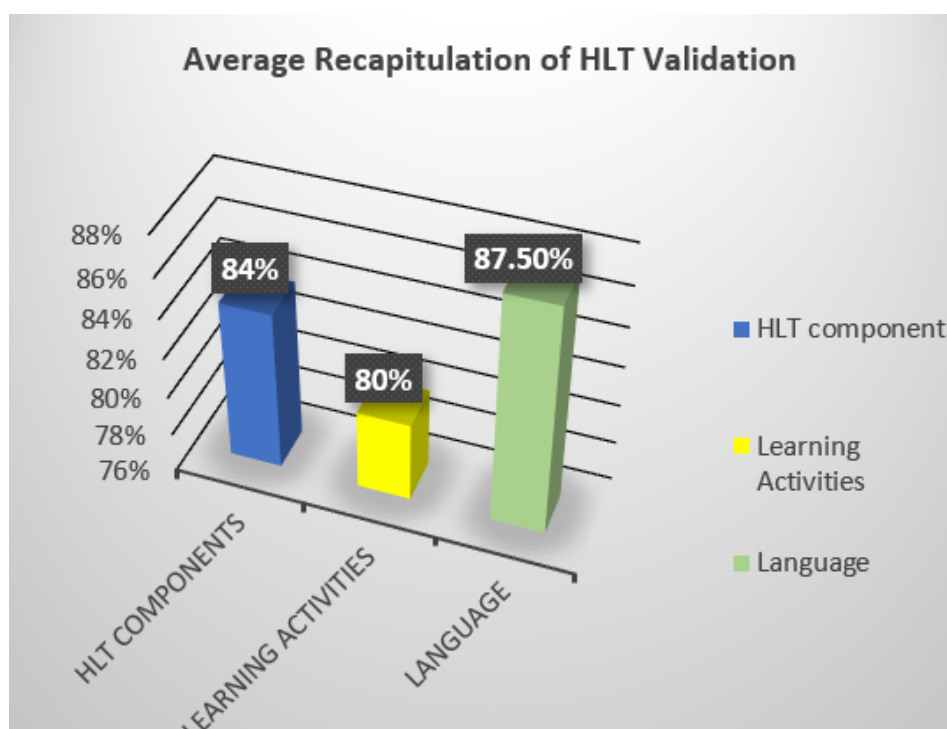


Figure 3. Average Recapitulation of HLT Validation Results based on Ethnomathematics of *Rumah Gadang* (Big House)

Quantitative data were obtained from validation sheets, while qualitative comments provided suggestions for improvement. The validation results indicated that the HLT was very valid, with an average score of 83,8 %, confirming its theoretical and practical feasibility. Minor revisions were made, including simplifying technical terms, reinforcing scaffolding strategies, and improving visual representations to make dimensions and angles more apparent. These adjustments aimed to make the material more inclusive for students with diverse ability levels. The results confirmed that the HLT, developed through the integration of RME principles, ethnomathematical contexts, and AR technology, was theoretically sound and ready for implementation in classroom settings.

Results of One-to-One Evaluation

The HLT developed in this study was designed to undergo a sequence of formative evaluations, including self-evaluation, expert review, one-to-one evaluation, small group testing, and field implementation. However, this paper reports only the findings from the one-to-one evaluation phase, while the results of the subsequent small group and field test phases will be presented in a separate publication.

This evaluation was conducted with three Grade VII students representing different ability levels – S1 (high), S2 (moderate), and S3 (low) – from SMPN 3 Batusangkar. The purpose was to assess the clarity, practicality, and engagement of the AR-supported learning activities.

During the sessions, students explored *Rumah Gadang* (Big House) components through AR applications, which enabled them to project 3D models, zoom in on ornaments, and rotate structures to observe geometric properties.

- S1 (high ability) worked independently, easily identifying triangles, rectangles, and circles in architectural parts with minimal guidance.
- S2 (moderate ability) followed instructions but occasionally required confirmation during measurement tasks; AR support helped visualize symmetry and translation.
- S3 (low ability) initially struggled to connect cultural objects with geometric concepts, but improved understanding after AR demonstrations and scaffolding support.

All students reported that AR made the activity more engaging and helped them connect geometry concepts to familiar cultural objects rather than abstract textbook figures.

Table 3. Recapitulation of the Results of the Identification of Mathematical Concepts by Students at *Rumah Gadang* (Big House)

No	Part of <i>Rumah Gadang</i> (Big House)	Identified Mathematical Concepts	Short Description
1	The <i>Gonjong</i> (roof ends)	Straight lines, taper corners	The curved shape upwards forms a tapered corner at the apex.
2	Support pole	Perpendicular lines, right angles	The position of the pole perpendicular to the floor forms a right angle.
3	Slanted wall board	Slash, dull corners	The tilt of the board creates a blunt angle to the floor.
4	Windows and doors	Rectangular, symmetry, folding	The shape of windows and doors resembles a rectangle with vertical symmetry.
5	Round Motif Carving Ornaments	Circle, circumference, and circumference area	The carving of the circle motif is calculated in circumference and width.
6	Flooring of the <i>Rumah Gadang</i> (Big House)	Square, rectangle, translation	The floor pattern consists of repeated square and rectangular shapes.
7	Ladder	Triangle, reawakening	The profile of the stairs forms a triangle that is built between the steps.
8	Space divider board	Parallel lines, intersections of lines	The guardrails are installed in parallel; some intersect.

All students reported that AR made the activity more engaging, particularly because it allowed them to “see” geometric concepts in familiar cultural objects rather than in abstract textbook figures.

Observed Outcomes

- Improved Identification: students could identify multiple geometric concepts in *Rumah Gadang* (Big House) more confidently.
- Enhanced Engagement: AR increased curiosity and motivation, especially for S2 and S3, who found static images less clear.
- Bridging Gaps: students with lower abilities required scaffolding, but AR helped reduce barriers by offering concrete visualizations.

Interview Results with Students

To complement the observations, semi-structured interviews were conducted with the three trial participants (S1-S3). The interviews aimed to capture students' perceptions of the AR-based ethnomathematics learning experience.

Language and Instruction Clarity

- S1 & S2 reported that the instructions in the worksheets were generally clear and easy to follow.
- S3 found some terms (e.g., identify and determine) difficult to understand. Simplification of vocabulary was recommended to ensure accessibility for students with lower literacy or mathematical ability.

Attractiveness of Display

- All three students appreciated the visual design of the worksheets, especially the photos and 3D AR models of *Rumah Gadang* (Big House).
- They suggested enlarging some images to make architectural details such as carvings and roof ornaments more visible and easier to analyze.

Technical and Cognitive Challenges

- S1 faced no major issues and found the AR interface intuitive.
- S2 occasionally needed confirmation when applying formulas for perimeter and area.
- S3 struggled with recalling formulas but stated that sample calculation steps would be helpful before solving the problems.

Relevance of Context

- All three students expressed that the use of *Rumah Gadang* (Big House) made mathematics learning more real and enjoyable.
- They emphasized that connecting lessons to familiar cultural objects reduced anxiety and increased their motivation compared to working on abstract textbook problems.

Key Insights from Interviews

- AR-based ethnomathematics activities increased student motivation and reduced feelings of difficulty in learning geometry.
- Cultural familiarity made the learning experience more meaningful and personal.
- Adjustments in language simplicity, image size, and scaffolded calculation steps are needed to make the materials more inclusive.

Observations and interviews indicated that students improved their ability to identify geometric shapes, showed increased motivation, and experienced decreased math anxiety. While the current report is limited to individual findings, the HLT design incorporated small-group evaluation and classroom field evaluation to evaluate broader impacts on student learning outcomes.

DISCUSSION

The findings of this study highlight the effectiveness of integrating RME-based Hypothetical Learning Trajectories with ethnomathematical contexts drawn exclusively from the *Rumah Gadang* (Big House) of the Minangkabau culture in West Sumatra, supported by AR technology. The integration of cultural artifacts and technological media fostered students' engagement, facilitated conceptual understanding, and connected mathematical ideas with meaningful real-world experiences. These results reinforce the argument that mathematics learning becomes more powerful when grounded in students' cultural contexts.^(39,67,69,77,78,79)

Ethnomathematical Context of Rumah Gadang and Its Influence on Learning

The ethnographic analysis of the *Rumah Gadang* (Big House) revealed rich mathematical structures embedded

within its architecture, such as proportionality in staircases, symmetry in roof forms, and geometric patterns in wall carvings. When these elements were used as learning contexts, students could more easily visualize abstract geometry concepts and relate them to familiar cultural forms. This aligns with the perspectives and view that mathematics is a set of human activities arising from cultural practices and perspectives, and that ethnomathematics bridges the gap between cultural identity and academic mathematics.^(77,80)

Students' reflections during the one-to-one evaluation supported this interpretation. For instance, one student explained that rotating a 3D *Rumah Gadang* (Big House) ornament in AR helped them understand reflection more clearly. Such experiences show how cultural familiarity and interactivity combine to promote engagement and understanding outcomes that are often difficult to achieve through abstract textbook instruction alone.^(81,82)

RME Principles through Ethnomathematical and AR Integration

The RME-based HLT designed in this study guided students to move progressively from contextual experience to formal abstraction through activities inspired by the *Rumah Gadang* (Big House). The principle of guided reinvention was realized as students rediscovered geometric concepts such as translation and reflection through exploration of architectural patterns. The emergent modelling process was supported by AR, which allowed interactive manipulation and 3D visualization of the cultural artifacts.

This synergy between ethnomathematical grounding and technological support demonstrates how RME principles can be contextualized in culturally meaningful ways. The results align with previous research emphasizing that contextualized and technology-supported learning environments enhance student motivation and spatial reasoning.^(83,84) The present study extends these findings by situating such learning within the Minangkabau *Rumah Gadang* (Big House), illustrating how cultural heritage can function as a didactical context for formal mathematical learning.^(21,65,67)

Validation and Evaluation of the HLT

The validation process, involving five experts from mathematics education, educational technology, and linguistics, indicated that the HLT was highly valid (83,8 %). Experts acknowledged that embedding mathematical concepts within cultural contexts improved conceptual coherence and learner accessibility, supporting the framework of design validity and practicality.⁽⁷⁴⁾ The HLT was developed to undergo a sequence of formative evaluations, including self-evaluation, expert review, one-to-one evaluation, small group evaluation, and field implementation.⁽⁷²⁾ However, this paper reports only the findings from the one-to-one evaluation phase, while results from the subsequent small group and field test phases will be presented in future publications. In the one-to-one evaluation, students demonstrated increased engagement, stronger conceptual understanding, and reduced anxiety toward geometry. The AR-supported activities allowed learners to visualize and manipulate shapes directly within familiar contexts, leading to more meaningful conceptual construction.^(55,75,85)

Theoretical and Practical Contributions

Theoretically, this study contributes to the development of domain-specific instructional theory within design research by illustrating how the cultural characteristics of the *Rumah Gadang* (Big House) can be systematically incorporated into formal mathematics learning. Rather than treating ethnomathematics as an add-on or comparative topic, this study situates it at the core of the instructional design process. This localized approach provides depth and clarity to how cultural context mediates mathematical understanding in Minangkabau learners.^(6,13,82,86,87,88,89,90,91,92,93) Practically, the study demonstrates that AR-supported, RME-based instruction using ethnomathematical contexts can help teachers design more engaging and meaningful geometry lessons. The resulting HLT aligns with the curriculum's emphasis on contextualized, student-centered learning that values local culture and technology integration.⁽⁹⁴⁾ The use of *Rumah Gadang* (Big House) as a learning context exemplifies how mathematics education can promote both cognitive growth and cultural appreciation.

CONCLUSIONS

This study demonstrated the powerful synergy between Realistic Mathematics Education principles, ethnomathematics, and augmented reality in designing hypothetical learning trajectories. Rooted in the cultural context of the *Rumah Gadang* (Big House), the learning design successfully connected students' lived experiences with formal mathematics concepts. First, the ethnomathematical exploration revealed that Indonesian traditional architecture contains rich mathematical knowledge, including geometry, proportional reasoning, and transformation concepts, which can serve as authentic contexts for school mathematics. Second, the RME-based HLT provided a structured pathway guiding students from concrete cultural observations to abstract mathematical reasoning. Validation by experts confirmed its theoretical soundness and pedagogical feasibility. Third, classroom trials showed that AR technology enhanced students' ability to identify geometric concepts, increased engagement across various ability levels, and reduced mathematics anxiety. Student interviews

further confirmed that learning became more meaningful and culturally relevant. These findings imply that combining pedagogy, culture, and technology offers a transformative model for mathematics education. For educators, it provides a replicable framework for designing culturally responsive and technologically enriched lessons. For policymakers, it highlights the importance of integrating indigenous knowledge systems and digital tools into curricula and teacher preparation. Although this research was conducted in the Indonesian context, the approach can be adapted to diverse cultural settings. Future studies should examine the long-term effects of RME-AR integration, explore additional cultural artifacts, and develop more advanced AR features to support inclusive learning. In conclusion, mathematics education becomes more rigorous, accessible, and identity-affirming when rooted in cultural heritage, reinforced by research-based pedagogy, and supported by suitable technologies.

LIMITATIONS AND FUTURE DIRECTIONS

The study intentionally focused on the *Rumah Gadang* (Big House) to ensure cultural and methodological coherence. Future investigations could explore other Minangkabau architectural variations or ornaments within West Sumatra while maintaining the focus within the same cultural domain. Such work could refine the understanding of how ethnomathematical elements from a single cultural heritage can inform instructional design and support the national agenda of culturally grounded education.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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