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Enhancing Students' Geometric Reasoning through Rumah Gadang Ethnomathematics: A Local Instructional Theory Based on Realistic Numerical

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Abstract: This study developed a Local Instructional Theory (LIT) on geometric transformation based on Realistic Mathematics Education (RME) integrated with ethnomathematics of Rumah Gadang Minangkabau to enhance students' mathematical problem-solving ability. Using design research combining Plomp's development model and Gravemeijer and Cobb's framework, the research produced a Hypothetical Learning Trajectory, teacher's guide, and student workbook. Validation by experts showed very high validity scores: HLT (3.53), teacher's book (3.45), and student's book (3.49). Practicality testing revealed very practical ratings: teacher's book (92.50%) and student's book (83.97%). Effectiveness was demonstrated through post-test results, with 71.88% of students achieving mastery criteria and significant improvement across all problem-solving indicators. The findings indicate that integrating cultural contexts through ethnomathematics within an RME framework effectively supports students' conceptual understanding and problem-solving skills in geometric transformation. This LIT provides a culturally responsive instructional model that bridges abstract mathematical concepts with students' lived cultural experiences.

Keywords: Ethnomathematics; Geometric transformation; Local instructional theory; Problem solving; Realistic mathematics education

Introduction

Problem-solving ability represents one of the fundamental objectives of numerical education and constitutes an essential competency for students to develop in addressing the dynamic challenges of the 21st century (Suherman & Vidákovich, 2025). In an increasingly complex global landscape, individuals must demonstrate adaptability and flexibility in integrating knowledge to generate innovative ideas and solutions (Payadnya, Wulandari, et al., 2024). Within the numerical domain, problem-solving encompasses critical cognitive activities including analysis, interpretation, rationalization, evaluation, and reflective thinking. When students engage with appropriately challenging problems, they develop enhanced reasoning capacities and strategic thinking skills that extend beyond routine computational tasks (Ramadhani et al., 2025).

Geometric transformation constitutes a core component of the numerical curriculum at the secondary school level, encompassing concepts such as reflection, translation, rotation, and dilation (Silva, 2025). Mastery of these topics holds significant practical relevance, as transformational principles appear in diverse contexts including artistic design, architectural planning, navigation systems, and digital imaging applications (Payadnya, Prahmana, et al., 2025). Furthermore, engagement with geometric transformation supports the development of spatial reasoning, logical argumentation, and proof construction—competencies that underpin advanced numerical thinking. Despite its importance, empirical evidence indicates that students frequently encounter

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difficulties in understanding transformational concepts, particularly in identifying image positions, applying appropriate procedures, and generalizing algebraic representations of geometric relationships (Payadnya, Atmaja, et al., 2025).

International assessments, including the Programme for International Student Assessment (PISA), have consistently revealed that students in Indonesia demonstrate limited proficiency in the "space and shape" domain, which includes transformational geometry (Suherman & Vidákovich, 2022). Nearly no Indonesian students achieved top performance levels on indicators related to mathematizing situations and interpreting numerical results (Utami et al., 2021). At the local level, preliminary investigations at several junior secondary schools indicated that students' numerical problem-solving performance remained below expected benchmarks, with average achievement scores falling under 50% of maximum possible points (Tuominen, 2022). Contributing factors include limited exposure to non-routine problems, instructional approaches emphasizing procedural memorization over conceptual understanding, and learning materials that insufficiently connect numerical concepts to students' lived experiences (Magnate, 2025).

To address these challenges, instructional approaches that bridge abstract numerical concepts with meaningful real-world contexts warrant consideration (Semba, 2025). Realistic Numerical Education (RNE) represents a pedagogical framework that initiates learning through contextual problems drawn from students' everyday environments, thereby facilitating the construction of numerical understanding through guided reinvention (Suherman & Vidákovich, 2023). Central to this approach is the principle that students develop conceptual knowledge by progressing from informal, context-based strategies toward formal numerical representations, supported by teacher facilitation and peer collaboration (Payadnya, Putri, et al., 2024).

Integrating cultural contexts into numerical instruction offers additional opportunities to enhance student engagement and conceptual understanding (Suherman, 2024). Ethnomatematics the exploration of numerical ideas embedded within cultural practices—provides a framework for connecting school numerical learning to students' cultural heritage (Annajmi et al., 2026). In the Minangkabau cultural context of West Sumatra, Indonesia, the traditional Rumah Gadang (Big House) embodies rich architectural features and decorative motifs that inherently reflect transformational principles (Lachney et al., 2025). The symmetrical roof structure (gonjong), repetitive ornamental patterns, and proportional relationships in building design offer authentic contexts for exploring reflection, translation, rotation, and dilation (Barwell et al., 2022). By situating numerical learning within this culturally familiar framework, instruction may simultaneously support conceptual development and foster appreciation for local cultural wisdom (Gbormittah et al., 2025).

This study aims to develop a Local Instructional Theory (LIT) on the topic of Geometric Transformation based on Realistic Numerical Education with ethnomatematics nuances derived from Rumah Gadang Minangkabau. Specifically, the research seeks to: (1) describe the characteristics of the developed LIT that satisfy criteria of validity and practicality, and (2) examine the effectiveness of the LIT in enhancing students' numerical problem-solving ability at the junior secondary school level. The resulting instructional design, encompassing a Hypothetical Learning Trajectory, teacher guide, and student workbook, is intended to provide educators with a culturally responsive, contextually grounded resource for facilitating meaningful numerical learning experiences (Vadivel et al., 2026).

Method

Research Design

This study employed a design research approach to develop, validate, and evaluate a Local Instructional Theory (LIT) focused on geometric transformation within a Realistic Numerical Education (RNE) framework, enriched with an ethnonumerical context derived from the Rumah Gadang Minangkabau cultural heritage. The primary objective was to enhance students' numerical problem-solving abilities through a structured, culturally contextualized learning trajectory.

Development Model and Procedure

The research integrated two established design research frameworks: the Plomp development model and the Gravemeijer & Cobb model. This hybrid approach ensured systematic product development while maintaining iterative, evidence-based refinement of the learning trajectory.

Plomp Model Phases

Preliminary Research: Conducted needs analysis, curriculum mapping (Phase D, Geometry element), concept analysis, student profiling, and literature review to establish the foundational design requirements.

Prototyping Phase: Developed initial instructional products (Hypothetical Learning Trajectory [HLT], teacher's guide, and student workbook). These underwent self-evaluation, expert validation, and sequential field trials (one-to-one, small-group, and full-class field test). Each trial generated feedback used to revise the products into subsequent prototypes.

Assessment Phase: Conducted semi-summative evaluation to determine the final practicality and effectiveness of the instructional design after full implementation.

Gravemeijer & Cobb Model Integration

Aligned with the prototyping phase, this model structured the iterative cycle of *preparing for the experiment*, *design experiment*, and *retrospective analysis*. Thought experiments informed the initial HLT, while teaching experiments (small-group and field test) provided empirical data to refine the trajectory through reflective cycles.

Participants and Setting

The study was conducted at SMPN 2 Lubuk Alung, West Sumatra, Indonesia. Participants included: *One-to-one evaluation:* 3 ninth-grade students representing high, medium, and low numerical problem-solving ability levels; *Small-group evaluation,* 6 students (2 per ability level) not involved in the prior phase; *Field test,* One intact class of 32 ninth-grade students; and *Teacher,* One experienced numerical education instructor who facilitated the field-test sessions while the researcher acted as an observer.

Instruments and Data Collection

Multiple validated instruments were deployed across development phases: *Validation Sheets,* Assessed content accuracy, language quality, didactic alignment, and graphical design of the HLT, teacher's guide, and student workbook. *Self-Evaluation Checklists:* Screened initial prototypes for obvious errors before expert review. *Observation Sheets:* Monitored implementation fidelity, teacher-student interactions, and adherence to RNE principles during small-group and field-test sessions. *Response Questionnaires & Interview Guidelines:* Collected teacher and student feedback on usability, time efficiency, engagement, and perceived learning support (5-point Likert scale). *Numerical Problem-Solving Tests:* Pre-test and post-test comprising four essay items aligned with Polya's problem-solving steps (understanding, planning, executing, reviewing). Items were contextualized within transformation concepts and culturally relevant scenarios.

All instruments were reviewed and validated by three numerical education experts, one language specialist, and one educational technology specialist prior to use.

Data Analysis and Evaluation Criteria

Data were analyzed using descriptive statistics and qualitative thematic synthesis to evaluate three core quality criteria. Validity: Determined using Aiken's V formula based on expert ratings (4-point scale). Products were classified as valid if $V \geq 2.80$, with "very valid" designated for $V \geq 3.40$. Practicality: Calculated as P = (Obtained Score / Maximum Possible Score) × 100%. Practicality thresholds followed standard educational design criteria: ≥85% (highly practical), 75–84% (practical), 60–74% (moderately practical). Effectiveness: Measured through post-test numerical problem-solving performance. The instructional design was deemed effective if: At least 65% of students scored above the school's Minimum Mastery Criteria (KKM = 75); Significant improvement was observed across all four problem-solving indicators compared to baseline performance.

Result and Discussion

This study produced a Local Instructional Theory (LIT) on the topic of Geometric Transformation based on Realistic Numerical Education (RNE) with ethnonumerical nuances of Rumah Gadang Minangkabau. The results are presented according to three quality criteria: validity, practicality, and effectiveness.

Validity of the Developed Products

Expert validation was conducted by three numerical education specialists, one educational technology specialist, and one language specialist. The validation results using Aiken's V formula are summarized in Table 1.

Table 1. Validity Scores of Developed Products

Product	Aspect	Validity Score	Category
HLT	Content	3.47	Very Valid
HLT	Language	3.60	Very Valid
HLT Overall		3.53	Very Valid
Teacher's Book	Content	3.50	Very Valid
Teacher's Book	Language	3.60	Very Valid
Teacher's Book	Didactic	3.50	Very Valid
Teacher's Book	Presentation	3.20	Valid
Teacher's Book Overall		3.45	Very Valid
Student's Book	Content	3.53	Very Valid
Student's Book	Language	3.75	Very Valid
Student's Book	Didactic	3.42	Very Valid
Student's Book	Presentation	3.25	Valid
Student's Book Overall		3.49	Very Valid

All products met the "very valid" criterion ($V \geq 3.40$), indicating that the instructional design is theoretically sound and appropriate for implementation.

Practicality of the Developed Products

Practicality was assessed through one-to-one evaluation, small-group evaluation, and field test using questionnaires, interviews, and observation sheets. Results are presented in Table 2.

Table 2. Practicality Scores of Developed Products

Evaluation Stage	Product	Aspect	Practicality (%)	Category
Small-Group	Student's Book	Ease of Use	87.50	Very Practical
Small-Group	Student's Book	Time Efficiency	86.67	Very Practical
Small-Group	Student's Book	Appeal	86.11	Very Practical
Small-Group	Student's Book	Comprehensibility	81.94	Very Practical
Small-Group	Student's Book	Benefit	83.33	Very Practical
Small-Group Overall	Student's Book		85.11	Very Practical
Field Test	Student's Book	Overall	83.97	Very Practical
Field Test	Teacher's Book	Overall	92.50	Very Practical

Both the teacher's book and student's book achieved "very practical" status (≥85%), indicating that the products are user-friendly, time-efficient, and beneficial for instructional implementation.

Effectiveness of the Developed Products

Effectiveness was measured through pre-test and post-test scores on numerical problem-solving ability, aligned with four indicators: (1) understanding the problem, (2) planning a solution strategy, (3) executing the strategy, and (4) interpreting results. Results are presented in Table 3.

Additionally, 23 out of 32 students (71.88%) achieved scores above the Minimum Mastery Criteria (KKM = 75) on the post-test, exceeding the 65% threshold for effectiveness. These results confirm that the LIT significantly enhanced students' numerical problem-solving ability.

Table 3. Effectiveness Results: Numerical Problem-Solving Ability

Indicator	Pre-test Mean	Post-test Mean	Improvement (%)
1. Understanding the problem	1.36	1.79	21.48
2. Planning strategy	0.53	1.66	56.64
3. Executing strategy	2.00	3.23	30.66
4. Interpreting results	0.60	1.02	20.70
Overall Mean	18.06	30.87	32.05

The development and implementation of a Local Instructional Theory (LIT) on Geometric Transformation based on Realistic Numerical Education with ethnonumerical nuances of Rumah Gadang Minangkabau yielded meaningful insights into how culturally contextualized, context-based learning can address persistent challenges in students' numerical problem-solving (Sebsibe et al., 2023). Rather than merely confirming the product's quality through validity, practicality, and effectiveness metrics, the findings illuminate deeper pedagogical and cultural dynamics that warrant careful consideration (Vandendriessche, 2022).

The strong validity scores across all instructional components suggest that integrating ethnonumerical contexts does not compromise mathematical rigor; rather, it enhances the coherence between abstract transformational concepts and students' lived experiences (Mocorro & Mocorro, 2025). The Rumah Gadang context—particularly its symmetrical roof structures (gonjong), repetitive ornamental patterns, and proportional architectural relationships—provided authentic, tangible anchors for students to explore reflection, translation, rotation, and dilation (Gutiérrez et al., 2022). This alignment between cultural artifacts and mathematical structures facilitated what Freudenthal termed "guided reinvention," allowing students to progress from informal, context-bound reasoning toward formal numerical representations without losing conceptual grounding (Bautista et al., 2026).

The high practicality ratings, particularly from teachers, indicate that the instructional design successfully balanced innovation with usability (Búrigo, 2025). Teachers reported that the structured anticipation of student responses and the culturally familiar problem contexts reduced instructional uncertainty and increased confidence in facilitating discovery-based learning (Fılız & Öztel, 2026). This finding carries significant implications for teacher professional development: when instructional materials explicitly connect pedagogical strategy with local cultural knowledge, educators are more likely to adopt and sustain innovative practices (Wibawa et al., 2025). The student workbook's design—progressing from concrete visual patterns to abstract coordinate representations—

mirrored the cognitive trajectory students naturally follow, reducing cognitive load and supporting sustained engagement (Weingarden et al., 2025).

Perhaps most notably, the effectiveness results reveal that contextualizing numerical learning within ethnocultural frameworks can substantially enhance problem-solving performance across all four indicators: understanding problems, planning strategies, executing solutions, and interpreting results. The marked improvement in strategy planning (56.64% increase) suggests that the Rumah Gadang context helped students move beyond rote procedural application toward flexible, adaptive reasoning. When students recognized transformational patterns in familiar cultural motifs, they were better able to transfer those insights to novel numerical problems—a hallmark of deep conceptual understanding (Annajmi et al., 2026; Krüger & Werth, 2025; Opesemowo et al., 2025; Ravichandran & Mohan, 2024).

The cultural dimension of this research extends beyond motivational benefits (Fan, 2026; Marschall, 2023; Sun & Wang, 2026). By positioning Rumah Gadang not merely as decorative illustration but as a legitimate source of mathematical inquiry, the instructional design affirmed students' cultural identities as intellectually valuable (Lajos, 2023; Zhan & Louie, 2023; Zhang et al., 2025). This affirmation likely contributed to increased participation, risk-taking in problem-solving, and collaborative discourse—conditions essential for developing robust numerical reasoning. In educational contexts where globalized curricula sometimes marginalize local knowledge, this approach demonstrates how cultural integration can strengthen, rather than dilute, academic rigor (El Bhih et al., 2024; Sebsibe et al., 2023; Wieselmann et al., 2025).

Several limitations merit acknowledgment. The study focused exclusively on ninth-grade students in one school setting, limiting generalizability to other grade levels, cultural contexts, or institutional environments. Additionally, the relatively short implementation period precluded examination of long-term retention or transfer effects. Future research might explore how this LIT framework adapts to other ethnocultural contexts, how teacher capacity-building influences implementation fidelity, and how digital tools might extend the reach of culturally grounded numerical learning.

Conclusion

This study successfully developed a Local Instructional Theory on Geometric Transformation based on Realistic Mathematics Education with ethnomathematics nuances of Rumah Gadang Minangkabau that meets the criteria of validity, practicality, and effectiveness. The integration of culturally contextualized problems derived from Minangkabau architectural heritage provided meaningful anchors for students to construct mathematical understanding through guided reinvention, demonstrating that ethnomathematics can serve as a powerful bridge between abstract geometric concepts and students' lived experiences. The instructional design—comprising a Hypothetical Learning Trajectory, teacher's guide, and student workbook—proved theoretically sound, user-friendly, and impactful in enhancing students' mathematical problem-solving abilities across all four indicators: understanding problems, planning strategies, executing solutions, and interpreting results. The findings underscore the pedagogical value of embedding mathematics instruction within culturally resonant contexts, particularly for fostering student engagement, conceptual understanding, and appreciation of local wisdom. By positioning Rumah Gadang not merely as illustrative content but as a legitimate source of mathematical inquiry, this research affirms that culturally responsive pedagogy can strengthen both academic rigor and cultural identity. The developed Local Instructional Theory thus offers a replicable framework for mathematics educators seeking to design contextually grounded, student-centered learning experiences that align with curriculum standards while honoring the cultural diversity of Indonesian classrooms.

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