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Ethnomathematics in elementary education: A systematic review of pedagogical approaches, technological innovation, and global implementations

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Abstract

Ethnomathematics, which integrates mathematical practices grounded in cultural traditions, has gained prominence as an approach to fostering culturally responsive learning in elementary mathematics education. This systematic review synthesizes 65 peer-reviewed empirical studies published between 2020 and 2025, examining its implementation across diverse global contexts. The analysis is organized around three domains: pedagogical approaches incorporating local narratives, cultural artifacts, and Indigenous knowledge; technological innovations, including digital modules, augmented reality, and mobile learning platforms; and comparative curricular frameworks across countries such as Indonesia, Brazil, Thailand, the United States, Mexico, Zimbabwe, Nigeria, Israel, and the Middle East. These contexts were selected based on their representation in the reviewed literature and relevance to the study's focus. Findings indicate that culturally grounded instruction enhances student engagement, problem-solving, and mathematical literacy, often with moderate to large effect sizes. Technology integration expands access and relevance, though digital inequities persist. Cross-national variation is evident. Key challenges include limited authentic resources, fragmented teacher development, and lack of standardized assessment. Future research should prioritize longitudinal studies and AI-supported learning environments.

Keywords: cultural integration and indigenous knowledge; culturally responsive pedagogy; elementary education; mathematical literacy; technology-enhanced learning

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Introduction

Elementary mathematics education plays a pivotal role in shaping learners' foundational numeracy (Dierkx et al., 2025), mathematical reasoning (Smit et al., 2023), and problem-solving (Santos-Trigo, 2024) capacities that support long-term academic trajectories and societal participation. Yet, a substantial body of research indicates that conventional mathematics instruction—often emphasizing procedural fluency detached from learners lived experiences—continues to produce uneven and frequently inequitable outcomes, particularly for students from culturally and linguistically diverse backgrounds (Pratama & Afriani, 2025; Supriyadi et al., 2024). Such instruction has been associated with persistent achievement gaps, limited learner engagement, superficial conceptual understanding, and restricted transfer of mathematical knowledge beyond the classroom (Harding, 2021; Payadnya, Wulandari, et al., 2024). These concerns have prompted sustained scholarly attention toward pedagogical approaches that position mathematics learning as culturally situated rather than culturally neutral.

Ethnomathematics has emerged as a prominent theoretical and pedagogical response to this challenge. Broadly defined, ethnomathematics examines mathematical ideas, practices, and forms of reasoning embedded in the cultural activities, artifacts, and problem-solving traditions of specific communities (Batiibwe, 2024, 2025). Central to this perspective is the recognition that mathematics is not a universal and value-free body of knowledge, but rather a socially constructed discipline shaped by historical, cultural, and epistemological contexts (Nasrum et al., 2025). From this standpoint, integrating local narratives, indigenous knowledge systems, and community practices into mathematics instruction has the potential to enhance learners' conceptual understanding, engagement, and mathematical identity formation, while simultaneously challenging deficit-oriented views of cultural diversity (Nuryadi et al., 2023; Sutarto et al., 2022).

The integration of ethnomathematics into classroom practice is theoretically informed by several intersecting frameworks. Sociocultural constructivism conceptualizes mathematical learning as a mediated activity, shaped by interaction, language, and participation within culturally organized practices (Payadnya, Wulandar, et al., 2024; Pratama & Afriani, 2025). Culturally responsive pedagogy emphasizes the strategic use of learners' cultural and linguistic resources as assets for learning rather than obstacles (Harding, 2021). Ethnomodeling further provides a methodological bridge between community-based mathematical knowledge and formal school mathematics through processes of representation, abstraction, and generalization (Magnate, 2025; Rosa & Orey, 2024). Collectively, these perspectives underscore that mathematical meaning-making is inseparable from the cultural contexts in which it occurs (Nasrum et al., 2025; Pratama & Afriani, 2025).

Since 2020, research on ethnomathematics in elementary education has expanded markedly in both volume and geographic distribution, with particularly strong growth in Indonesia, Brazil, and Thailand (Deda et al., 2024; Giordano et al., 2023; Nasrum et al., 2025). This expansion has been accompanied by increasing experimentation with technology-enhanced ethnomathematics, including digital learning modules, augmented reality, simulations, and mobile platforms—developments accelerated by the COVID-19 pandemic (Gumede & Badriparsad, 2022; Mumpuni & Marsigit, 2022; Patri & Heswari, 2021). While

such technologies have broadened access to culturally contextualized learning, especially in remote or underserved contexts (Aziz & Suprayitno, 2022; Silva & Oliveira, 2024), they have also highlighted persistent inequities related to digital infrastructure and the uneven availability of culturally authentic resources (Astuti et al., 2024; Cayabas & Sumeg-ang, 2023).

Despite this growing body of work, the literature remains fragmented in important ways. Existing reviews tend to focus on isolated pedagogical strategies or single national contexts, offering limited insight into how ethnomathematics operates across pedagogical, technological, and curricular-policy dimensions simultaneously (Kyeremeh et al., 2023). Moreover, recurring challenges—such as limited culturally grounded instructional materials (Purwanto et al., 2025), fragmented teacher professional development (Batiibwe, 2025; Fendrik et al., 2025; Furuto, 2021), a lack of culturally valid assessment instruments (Ramadhani et al., 2025; Suherman & Vidákovich, 2025), and ambiguous curricular guidance (Purwanto et al., 2025)—continue to constrain systematic implementation. Notably, there remains a paucity of integrative analyses that examine how these challenges interact across contexts and over time, as well as limited attention to longitudinal outcomes, cross-cultural comparisons, and emerging technological possibilities (Maharani et al., 2024; Semerikov et al., 2025; Sutarto et al., 2022).

Addressing these gaps, the present systematic review makes a distinct contribution by offering a multidimensional synthesis of ethnomathematics research in elementary education. Drawing on 65 peer-reviewed empirical studies published between 2020 and 2025, this review moves beyond descriptive aggregation to examine how pedagogical designs, technological affordances, and curricular-policy frameworks intersect across diverse global contexts. By systematically comparing implementation patterns across regions and methodological traditions, this review advances current understanding of not only whether ethnomathematics works, but how, under what conditions, and with what systemic supports it is most likely to be sustained. In doing so, the study provides theoretically informed and empirically grounded insights to support future research, curriculum development, teacher education, and policymaking in culturally responsive mathematics education.

Theoretical framework

Ethnomathematics, as both a pedagogical orientation and a research perspective, is grounded in several intersecting theoretical traditions that collectively illuminate how mathematical knowledge is produced, mediated, and learned within specific cultural contexts (Rosa et al., 2016). Rather than treating these perspectives as discrete or competing frameworks, this study conceptualizes them as complementary lenses that converge on shared assumptions about the sociocultural nature of mathematical meaning-making (Norberg, 2023). Together, these frameworks provide the conceptual foundation for understanding not only whether ethnomathematics supports elementary mathematics learning, but how, why, and under what conditions such support emerges across diverse educational systems.

Sociocultural constructivism positions learning as an inherently social and culturally mediated process, shaped through interaction, language, and participation in meaningful practices (Budwig et al., 2023; Taber, 2024). From this perspective, mathematical

understanding does not develop in isolation, but through learners' engagement with culturally situated tasks, dialogic interaction with peers and teachers, and the use of mediating artifacts that carry social meaning (Ben-Dor & Heyd-Metzuyanim, 2025). In elementary mathematics education, this implies that students construct robust mathematical understanding when instruction connects formal concepts to familiar cultural activities and everyday experiences (Clements et al., 2023). Sociocultural constructivism thus provides a foundational theoretical rationale for ethnomathematics, framing mathematics learning as a process of situated participation rather than the acquisition of decontextualized procedures.

Culturally responsive pedagogy extends this sociocultural view by foregrounding learners' cultural identities, linguistic resources, and community knowledge as central pedagogical assets rather than peripheral contextual factors (Gulya & Fehervari, 2024). This framework emphasizes deliberate instructional practices that draw on students' cultural references, communication norms, and lived experiences to enhance engagement, relevance, and academic achievement. In elementary mathematics classrooms, culturally responsive pedagogy supports the use of local narratives, indigenous problem-solving strategies, and culturally meaningful artifacts as entry points for engaging with formal mathematical ideas (Bonney et al., 2026). Empirical research indicates that such practices contribute not only to improved learning outcomes, but also to the development of positive mathematical identities and a sense of belonging within mathematics learning communities.

Ethnomodeling provides a methodological bridge between community-based mathematical practices and formal school mathematics (Rosa & Orey, 2024). It involves identifying mathematical reasoning embedded in culturally significant activities—such as traditional crafts, games, commerce, or agricultural practices—and systematically connecting these practices to formal mathematical representations, abstractions, and generalizations. Rather than positioning academic mathematics as culturally neutral or hierarchically superior, ethnomodeling frames community mathematics and school mathematics as mutually informing domains. This process supports the indigenization of curricula, enabling students to develop competence in conventional mathematical forms while remaining anchored in culturally authentic knowledge systems.

Collectively, sociocultural constructivism, culturally responsive pedagogy, and ethnomodeling converge on a central premise: mathematics learning is most meaningful, equitable, and intellectually durable when it is situated within learners' cultural contexts and mediated through pedagogical practices that recognize culture as a core epistemic resource rather than a superficial add-on. Importantly, this integrated framework underscores that effective ethnomathematics implementation requires more than the insertion of cultural examples into existing curricula; it demands a reconceptualization of mathematics as culturally embedded knowledge and a reconfiguration of instructional design, assessment, and teacher mediation. Finally, guided by this integrated theoretical framework, the present systematic review is structured around the following research questions:

1. How do ethnomathematics-based pedagogical approaches, grounded in local narratives, cultural artifacts, and indigenous knowledge, influence elementary students' mathematical engagement, reasoning, and learning outcomes across sociocultural contexts? (RQ1)

2. How do sociocultural and culturally responsive processes—such as interaction, mediation, identity development, and participation—shape the implementation and effectiveness of ethnomathematics in elementary mathematics classrooms? (RQ2)
3. How are ethnomodeling practices and technology-enhanced tools (e.g., digital modules, mobile platforms, augmented reality) used to connect community-based mathematical knowledge with formal academic mathematics across different curricular and systemic contexts? (RQ3)

Methods

This study adopts a systematic qualitative synthesis design informed by the principles of systematic review and thematic analysis, situated within a critical narrative review framework (Depraetere et al., 2021). The review is guided by an explicit theoretical orientation grounded in sociocultural constructivism, culturally responsive pedagogy, and ethnomodeling, enabling a theory-driven examination of how ethnomathematics is conceptualized, enacted, and investigated in elementary mathematics education. Rather than adhering to a formal systematic review protocol such as PRISMA or conducting a meta-analysis, this approach prioritizes analytical depth and interpretive rigor. It is designed to generate nuanced insights into the pedagogical mechanisms, sociocultural mediational processes, and systemic conditions that shape the implementation of ethnomathematics across diverse contexts (Dixon-Woods et al., 2006; Sukhera, 2022).

Literature search strategy

To enhance transparency while retaining the narrative and interpretive nature of the review, a comprehensive literature search was conducted to identify peer-reviewed empirical studies published between January 2020 and December 2025. Searches were performed across major academic databases widely used in mathematics education research, including Scopus and Web of Science. These database searches were complemented by backward and forward citation tracking of key review articles and influential empirical studies in ethnomathematics and elementary education.

Search strategies employed combinations of keywords related to ethnomathematics and elementary education, including ethnomathematics, culturally responsive mathematics, Indigenous mathematics, elementary or primary education, technology-enhanced learning, and digital ethnomathematics. In addition, the reference lists of relevant reviews and seminal publications were manually examined to identify further studies that met the inclusion criteria, thereby ensuring comprehensive coverage of the literature.

Inclusion and exclusion criteria

Studies were included if they reported empirical research (qualitative, quantitative, or mixed-methods), focused on elementary or primary mathematics education, explicitly engaged with ethnomathematics, culturally grounded mathematics, or indigenous mathematical practices, were published in peer-reviewed journals between 2020 and 2025, and provided sufficient

methodological detail to support analytical interpretation. Studies were excluded if they were purely theoretical, focused exclusively on secondary or tertiary education, or did not substantively address mathematics learning or teaching.

Screening and study selection

The initial search yielded 312 records. After removing duplicates and screening titles and abstracts, 104 articles were retained for full-text review. Applying the inclusion criteria resulted in a final corpus of 65 studies. Screening decisions were documented systematically to enhance transparency and replicability.

Analytical framework and coding procedures

Data analysis followed a theory-driven thematic coding approach, with the three Research Questions serving as the primary analytical lenses. A coding framework was developed iteratively through deductive alignment with the theoretical framework and inductive engagement with the data.

1. RQ1 (Pedagogical Approaches and Learning Outcomes)
   Studies were coded for instructional design features (e.g., use of local narratives, artifacts, traditional games), targeted mathematical content, reported learning outcomes (engagement, reasoning, literacy), and evidence of effectiveness.
2. RQ2 (Sociocultural and Culturally Responsive Processes)
   Codes captured sociocultural mechanisms such as mediation, interaction patterns, identity development, participation structures, teacher roles, and student positioning within learning activities.
3. RQ3 (Ethnomodeling and Technology Integration)
   Coding focused on how community-based mathematical practices were modeled and connected to formal mathematics, as well as the role of digital tools (e.g., mobile apps, AR, digital modules) in supporting or constraining this process.
   Each study was coded across all relevant dimensions, allowing for cross-cutting analysis rather than categorical isolation.

Trustworthiness and Analytical rigor

To enhance trustworthiness, coding categories were refined through repeated comparison across studies and constant reference to the theoretical framework. Analytical memos were used to document coding decisions, emerging patterns, and theoretical interpretations. Attention was paid to contextual variation, avoiding overgeneralization across culturally distinct settings—a concern particularly salient in ethnomathematics research.

Methodological limitations

As with all systematic reviews, this study is limited by the scope and quality of available published research. Language restrictions and database coverage may have excluded relevant local studies, particularly from underrepresented regions. Additionally, heterogeneity in study

designs and outcome measures precluded formal meta-analysis, reinforcing the need for interpretive rather than purely statistical synthesis.

Results

The systematic review synthesizes 65 peer-reviewed empirical studies published between 2020 and 2025 that examine ethnomathematics in elementary education. The studies span diverse geographic contexts, with the largest representation from Indonesia (n = 18), followed by Brazil (n = 12), Thailand (n = 8), Zimbabwe (n = 6), Nigeria (n = 5), Israel (n = 5), Mexico (n = 4), the United States (n = 3), and the Middle East (n = 4). These contexts were identified based on their prevalence within the reviewed literature and their relevance to the analytical focus of the study, including several studies situated in the Middle East that did not specify particular national settings. Furthermore, given the scope and heterogeneity of the dataset, the review does not attempt exhaustive country-by-country comparisons. Instead, cross-contextual analysis is guided by the three research questions, enabling a more conceptually coherent and theory-driven synthesis of findings.

Methodologically, qualitative approaches predominate (n = 31), encompassing ethnographic case studies, interviews, and content analyses. Quantitative designs (n = 18) primarily employ quasi-experimental, pretest–posttest, and comparative group structures, while mixed-methods studies (n = 16) integrate quantitative outcome measures with qualitative process-oriented data. This methodological diversity supports a comprehensive examination of both learning outcomes and the underlying mechanisms shaping ethnomathematics implementation across contexts.

RQ1: Pedagogical approaches and learning outcomes

To address the first research question, we examined how ethnomathematics-based pedagogical approaches—grounded in local narratives, cultural artifacts, and indigenous knowledge systems—influenced elementary students' mathematical engagement and learning outcomes. Analysis of pedagogical integration strategies, measured learning outcomes, and affective impacts across the 65 studies revealed consistent patterns regarding both what educators implemented and what impacts such implementation produced. The findings presented below synthesize evidence regarding content integration, academic learning outcomes, and non-cognitive outcomes related to student engagement, identity, and sense of belonging.

Across the 65 reviewed studies, ethnomathematics-based pedagogical approaches consistently integrated local narratives, cultural artifacts, and indigenous problem-solving practices into elementary mathematics instruction (Harding, 2021; Nasrum et al., 2025; Payadnya, Wulandari, et al., 2024; Supriyadi et al., 2024). Instructional designs ranged from the incorporation of traditional games (e.g., Indonesia's *Tepuk Bergambar*) (Prahmana et al., 2012) to market-based simulations (Risdiyanti et al., 2019), temple structure (Nisa & Hidayati, 2024), and agricultural measurement tasks (Batiibwe, 2025). Empirical evidence indicates that these culturally embedded approaches enhance engagement, conceptual understanding, and mathematical reasoning compared to conventional procedural instruction, with moderate-to-large effect sizes reported in quasi-experimental and pre-post designs. Notably, students exposed to culturally contextualized tasks demonstrated increased capacity for problem-solving, flexible strategy use,

and transfer of mathematical ideas to novel situations. Cross-national patterns reveal systematic curricular integration in Indonesia, partial curricular alignment in Thailand, and fragmented implementation in Brazil, highlighting the importance of institutional support and curriculum coherence in translating pedagogical innovations into measurable learning outcomes.

Pedagogical strategies and content integration

Analysis revealed consistent patterns in how educators embedded ethnomathematics across elementary mathematics content areas. Studies documented integration of local narratives and cultural artifacts into geometry instruction (n = 14 studies), with particular emphasis on traditional patterns, symmetry, and spatial reasoning derived from indigenous crafts, textiles, and architectural practices. Numeracy and arithmetic instruction incorporated community-based practices such as traditional commerce, market-based transactions, and agricultural measurement systems (n = 12 studies). Problem-solving and reasoning activities leveraged traditional games, community challenges, and indigenous knowledge systems (n = 11 studies). Algebra and algebraic thinking were less frequently integrated with ethnomathematical content (n = 6 studies), representing a notable gap in current implementation.

Academic learning outcomes

Studies consistently documented positive effects of ethnomathematics-based instruction on elementary students' mathematical achievement and literacy. Quantitative studies (n = 18) reported effect sizes ranging from small to large when comparing ethnomathematics-enhanced instruction with conventional approaches, with a median effect size in the moderate-to-large range. Specifically, meta-analytic synthesis indicated that culturally embedded instruction improved problem-solving competencies (median Cohen's d = 0.65) and mathematical communication skills (median Cohen's d = 0.58) compared to procedurally focused conventional instruction (Turmuzi et al., 2024). Students' conceptual understanding of mathematical ideas, as assessed through open-ended tasks and literacy-based items, demonstrated stronger performance in ethnomathematics-engaged cohorts (n = 12 studies) (Pratama & Yelken, 2024). Creative thinking abilities, measured through assessments of mathematical flexibility and originality, showed enhancement in ethnomathematics contexts (n = 8 studies).

Non-cognitive and affective outcomes

Beyond academic achievement, ethnomathematics interventions yielded measurable improvements in students' affective and identity-related outcomes. Learner engagement and motivation consistently increased in ethnomathematics-enhanced classrooms (n = 15 studies), with qualitative evidence indicating that cultural relevance heightened students' sense of mathematical significance and personal connection to mathematical content. Mathematical identity formation, conceptualized as students' sense of themselves as "mathematics people" capable of mathematical thinking, showed strengthening in ethnomathematics contexts (n = 13 studies). Sense of belonging and reduced mathematics anxiety emerged as measurable outcomes in studies employing affective assessment instruments (n = 10 studies). Furthermore,

cultural affiliation and pride in indigenous knowledge systems were reinforced through ethnomathematics participation (n = 9 studies).

RQ2: Sociocultural processes and implementation factors

The second research question directed attention toward understanding the sociocultural mechanisms through which ethnomathematics supported learning and the systemic implementation factors shaping ethnomathematics integration across diverse educational contexts. This multifaceted investigation examined mediational processes operating within classroom interactions, teacher-level variables including professional development and pedagogical knowledge, curricular frameworks and institutional implementation models, and both barriers and facilitating factors constraining or enabling ethnomathematics adoption. The findings synthesized below illuminate how cultural participation, teacher capacity, institutional structures, and implementation conditions functioned individually and in concert to support or constrain ethnomathematics implementation.

Findings consistently demonstrate that sociocultural mediation, teacher facilitation, peer interaction, and culturally responsive scaffolding are critical mechanisms underpinning the success of ethnomathematics instruction. Teachers who deliberately leveraged students' linguistic resources, prior knowledge, and cultural practices created learning environments that fostered identity development, mathematical agency, and a sense of belonging. Observational and interview data suggest that classroom discourse, guided reinvention, and collaborative problem-solving were central to promoting conceptual understanding, particularly when students engaged in ethnomathematics tasks embedded in familiar cultural contexts. However, the implementation of culturally responsive pedagogy was often constrained by limited professional development, variable teacher knowledge of community-based practices, and insufficient culturally authentic resources, particularly in under-resourced regions. These findings highlight the importance of teacher capacity-building and systemic supports for sustaining ethnomathematics practices.

Mediational mechanisms and sociocultural processes

Qualitative and mixed-methods studies (n = 31 studies) documented specific sociocultural mechanisms through which ethnomathematics supported learning. Dialogic interaction and peer collaboration around culturally meaningful mathematical tasks emerged as central mediational processes (n = 18 studies). Students' deployment of home languages and cultural communication patterns in mathematical reasoning facilitated conceptual development and peer explanation (n = 12 studies). Community participation and connection between classroom mathematics and out-of-school mathematical practices appeared to strengthen transfer of learning (n = 10 studies). Teacher scaffolding that explicitly connected formal mathematical concepts to cultural practices functioned as a critical mediational bridge (n = 14 studies).

Teacher professional development and pedagogical content knowledge

Significant variation emerged across contexts regarding teacher preparation and ongoing professional development for ethnomathematics implementation. Studies conducted in Indonesia (n = 10) documented relatively robust professional development initiatives, though

implementation remained uneven. In Brazil (n = 8), teacher professional development was fragmented and often dependent on individual educator initiative rather than systematic institutional support. Thailand (n = 6) showed emerging professional development efforts with increasing institutional support. Zimbabwe, Nigeria, and Israel exhibited limited, project-based professional development rather than sustained, systemic programs. Across contexts, teachers reported insufficient preparation in culturally grounded pedagogical content knowledge—specifically, inadequate preparation in connecting community mathematics to formal mathematical representations and generalizations. Studies identified professional development gaps as a critical constraint on implementation fidelity and sustainability.

Curricular frameworks and implementation models

Indonesia demonstrated the most structured curricular integration of ethnomathematics, employing systematic implementation models including ADDIE (Analysis, Design, Development, Implementation, Evaluation), 4D (Define, Design, Develop, Disseminate), Realistic Mathematics Education (RME), Contextual Teaching and Learning (CTL), and Problem-Based Learning (PBL) frameworks. These structured models facilitated more consistent and replicable ethnomathematics integration (n = 14 studies from Indonesia) (Giordano et al., 2023; Mei et al., 2025; Putra et al., 2025; Sunzuma & Umbara, 2025; Susanti et al., 2025). Brazil encountered significant implementation challenges related to rigid national curricula and limited autonomy in instructional design (n = 10 studies). Thailand exhibited emerging curricular support and increasing administrative openness to innovation, though implementation remained less structured than Indonesia (n = 8 studies) (Payadnya, Wulandar, et al., 2024). Sub-Saharan African contexts (Zimbabwe, Nigeria) and Israel reported ad hoc implementation dependent on individual school initiatives rather than systemic curricular policy (n = 16 studies) (Aremu & Adebagbo, 2019; Chikodzi & Kaino, 2020; Maphosa et al., 2025; Mashoko, 2022; Wulandari et al., 2024).

Barriers and facilitating factors

Analysis identified consistent barriers constraining ethnomathematics implementation across contexts. Material scarcity—specifically, limited availability of culturally grounded, high-quality instructional resources—emerged as a primary constraint in 14 studies across all geographic regions. Absence of standardized, culturally valid assessment instruments that reliably measure ethnomathematics learning outcomes hindered systematic evaluation and accountability (n = 12 studies). Curricular ambiguity and lack of clear policy guidance regarding ethnomathematics integration constrained implementation at institutional and national levels (n = 10 studies). Facilitating factors included administrative and policy support for curricular innovation (strongest in Indonesia), availability of community partnerships and indigenous knowledge holders (variable across contexts), and teacher motivation grounded in commitment to equity and cultural responsiveness (evident in n = 18 studies).

RQ3: Ethnomodeling, technology integration, and knowledge bridging

The third research question examined how ethnomodeling practices and technology-enhanced tools functioned to bridge community-based mathematical knowledge with formal academic

mathematics across diverse curricular and systemic contexts. This multidimensional investigation encompassed analysis of ethnomodeling methodologies, technology tool deployment and impacts, and evidence regarding implementation sustainability and scalability (Verbruggen et al., 2021). The findings synthesized below illuminate how methodologies for connecting community mathematics to school mathematics operated in practice, how digital technologies expanded access while introducing new implementation challenges, and what systemic conditions supported or hindered long-term sustainability.

The reviewed studies illustrate that ethnomodeling—linking community-based mathematical knowledge with formal academic mathematics—was implemented both through traditional classroom activities and through technology-enhanced tools. Digital modules, mobile platforms, augmented reality, and interactive simulations facilitated representation, abstraction, and generalization of culturally situated mathematical practices. Evidence suggests that technology can enhance accessibility, provide dynamic visualizations, and extend engagement beyond the classroom, particularly in remote or resource-constrained contexts. Nonetheless, disparities in digital infrastructure and access to culturally relevant digital content remain significant barriers, emphasizing that technology serves as an enabler rather than a standalone solution. Importantly, studies integrating ethnomodeling with technology reported higher fidelity in the translation of community practices into formal mathematical reasoning, indicating that deliberate pedagogical design is critical to bridging cultural knowledge and school mathematics.

Ethnomodeling practices

Studies employing explicit ethnomodeling methodologies (n = 14 studies) systematically connected community-based mathematical practices to formal academic mathematics. These studies documented identification of mathematical reasoning embedded in culturally significant activities—including traditional textile production and batik design, traditional games and play, community-based economic exchange, agricultural measurement practices, and building and construction traditions. The most systematically documented ethnomodeling processes involved representation and abstraction phases, wherein community mathematical practices were translated into formal mathematical symbols, structures, and generalizations. However, n = 8 studies reported incomplete ethnomodeling sequences, in which community practices were incorporated but not systematically connected to formal mathematical concepts through explicit modeling and abstraction phases.

Technology integration and tool deployment

Technology-enhanced ethnomathematics expanded significantly post-pandemic, with n = 28 studies (43% of corpus) incorporating digital tools. Digital learning modules and e-modules delivering culturally contextualized mathematics content were deployed in n = 12 studies, predominantly in Indonesia and Brazil. Augmented reality (AR) applications enabling visualization of cultural artifacts and geometric patterns were documented in n = 6 studies, primarily in Indonesia. Mobile learning platforms and smartphone-based applications facilitating access to ethnomathematics resources in remote contexts were employed in n = 7 studies. Interactive simulations and computer-assisted instruction grounded in cultural scenarios appeared in n = 5

studies. Notably, n = 21 studies (33% of corpus) occurred in contexts with limited technology infrastructure, reflecting significant global variation in technology access.

Technology-enhanced ethnomathematics expanded potential reach, particularly for students in remote and resource-constrained environments. Studies conducted in rural Indonesia (n = 6) and Thailand (n = 4) documented improved access to culturally contextualized learning resources via mobile platforms and e-modules. However, persistent digital divides constrained equitable access and quality implementation. Limited availability of culturally authentic digital resources in non-English, non-dominant languages reduced technology's culturally responsive potential in n = 11 studies across Zimbabwe, Nigeria, and other African contexts. Technical limitations, including unstable internet connectivity and inadequate device availability, were documented as implementation barriers in n = 13 studies across lower-income regions. Importantly, n = 6 studies explicitly documented risks of cultural decontextualization when technology was deployed without attention to cultural authenticity and community input.

Evidence regarding long-term scalability remained limited. Longitudinal follow-up beyond 12 months was documented in only n = 4 studies. Studies assessing sustainability (n = 7) identified critical dependencies on ongoing teacher professional development, technical support infrastructure, and institutional commitment. Successful scaling appeared facilitated by structured curricular integration (as in Indonesia), policy support, and investment in community-responsive resource development.

Emerging trends and methodological considerations

A nascent but growing research domain explored artificial intelligence (AI) and immersive technologies for ethnomathematics learning environments (n = 4 studies). These exploratory investigations examined potential applications of AI for personalized, culturally adaptive learning and immersive virtual environments enabling students to engage with cultural practices and mathematical concepts in dynamic interaction. However, empirical evidence regarding efficacy remained preliminary.

Qualitative research (n = 31 studies) provided rich, contextually grounded accounts of ethnomathematics implementation mechanisms, student reasoning processes, and sociocultural factors supporting learning. Quantitative studies (n = 18) contributed rigorous outcome measurement and comparative effectiveness evidence. Mixed-methods investigations (n = 16) integrated these complementary strengths. However, substantial heterogeneity in measurement instruments, outcome definitions, and comparison groups limited quantitative synthesis; meta-analytic aggregation was feasible only for subsets of studies employing comparable designs and instruments.

Across all three domains, several patterns emerge. First, implementation effectiveness is tightly coupled with teacher expertise, curriculum alignment, and systemic support. Second, student engagement and identity development emerge as consistent outcomes when instruction is culturally situated and socially mediated. Third, while technology offers substantial affordances, persistent equity and access issues may limit its impact unless accompanied by comprehensive professional development and context-sensitive instructional design. Finally, geographic comparisons highlight that contextual specificity matters: what succeeds in

Indonesia may require adaptation to be effective in Brazil, Thailand, or other regions, reinforcing the centrality of culturally responsive and contextually grounded pedagogy.

Discussion

The present systematic review synthesized findings from 65 peer-reviewed empirical studies to examine ethnomathematics implementation in elementary education across diverse global contexts. Findings across all three research questions converge to substantiate and extend the integrated theoretical framework grounding this review—namely, that mathematical learning is most meaningful, equitable, and intellectually durable when authentically situated within learners' cultural contexts and supported by pedagogical practices that strategically leverage cultural diversity as a substantive intellectual asset. The empirical evidence systematically documented how sociocultural constructivism, culturally responsive pedagogy, and ethnomodeling operated in concert to support elementary students' mathematical development while simultaneously advancing affective, identity, and cultural objectives. However, the review also identified significant implementation challenges, persistent inequities, and critical research and practice gaps that constrain scaling of ethnomathematics initiatives globally.

Pedagogical effectiveness and learning outcomes

Findings from RQ1 demonstrated that ethnomathematics-based pedagogical approaches produced consistent, measurable improvements in elementary students' mathematical achievement, reasoning, and engagement compared to conventional, decontextualized instruction. Meta-analytic synthesis of quantitative studies indicated moderate-to-large effect sizes for problem-solving competencies ($d = 0.65$) and mathematical communication ($d = 0.58$), with particular strength in geometry and number-sense development wherein cultural artifacts and community practices most readily embedded mathematical concepts. These findings align with and extend prior research on culturally responsive pedagogy and culturally sustaining mathematics, suggesting that cultural integration functions not as a supplementary pedagogical enhancement but rather as a core mechanism supporting robust mathematical reasoning and achievement.

Beyond academic metrics, ethnomathematics significantly influenced elementary students' affective relationships with mathematics, mathematical identity, and sense of belonging. The documentation of strengthened mathematical identities, increased engagement, and reduced mathematics anxiety among ethnomathematics-engaged students—particularly striking among culturally and linguistically diverse learners historically marginalized in conventional mathematics instruction—represents a consequential finding with implications for educational equity and student agency. These affective and identity outcomes align with theoretical premises of culturally responsive pedagogy and sociocultural constructivism, which posit that learning is fundamentally intertwined with identity development and sense of belonging. The simultaneous achievement of academic and affective/identity objectives represents a distinctive contribution of ethnomathematics, distinguishing it from purely skills-focused instructional approaches (Suherman & Vidákovich, 2022).

However, notable gaps emerged regarding breadth of content integration. Geometry and numeracy were extensively integrated with ethnomathematics across studies, whereas algebra and algebraic thinking remained underrepresented (Ramadhani et al., 2025). This content-specific gap suggests both an opportunity and a challenge: ethnomathematics principles have not yet been systematically extended across all elementary mathematics content areas, potentially limiting the comprehensiveness and robustness of ethnomathematics' educational impact (Hendriyanto et al., 2023; Turmuzi et al., 2023). Future curriculum development and research must address this gap to fully realize ethnomathematics' potential across elementary mathematics.

Sociocultural mechanisms and implementation dynamics

Findings from RQ2 elucidated specific sociocultural mechanisms through which ethnomathematics supported learning, providing empirical validation of theoretical propositions underlying the review's framework. Qualitative and mixed-methods investigations documented that dialogic interaction, peer collaboration, strategic use of home languages and cultural communication patterns, and teacher scaffolding bridging cultural familiarity with mathematical abstraction functioned as central mediational processes. These findings substantiate sociocultural constructivist theory by demonstrating empirically how cultural participation, language, and interaction mediate mathematical meaning-making. The documentation that community connection and transfer of learning were strengthened when classroom mathematics authentically connected to out-of-school practices further validates the theoretical proposition that meaningful mathematical learning requires situated participation within communities of practice.

Yet RQ2 findings also illuminated substantial systemic barriers constraining ethnomathematics' institutionalization and sustainability. Teacher professional development emerged as a critical and insufficiently addressed implementation factor. Across geographic contexts, teachers reported inadequate preparation in culturally grounded pedagogical content knowledge, particularly regarding ethnomodeling—the process of connecting community mathematics to formal academic mathematics. This professional development gap represents a fundamental implementation bottleneck: even when theoretical understanding and pedagogical commitment are present, teachers lack preparation in the specific methodological competencies required for effective ethnomathematics implementation. The variation in professional development quality across contexts—with Indonesia demonstrating more robust, systematic initiatives compared to fragmented efforts in Brazil, Thailand, and particularly Sub-Saharan Africa and Israel—reflects broader patterns of educational investment inequality and has direct implications for implementation outcomes and sustainability (Amzaleg & Masry-Herzallah, 2022; Eliyahu-Levi & Ganz-Meishar, 2023).

Curricular frameworks substantially influenced ethnomathematics' consistency and institutionalization. Indonesia's systematic employment of structured implementation models (ADDIE, 4D, RME, CTL, and PBL) facilitated more consistent, replicable, and scalable ethnomathematics integration compared to ad hoc approaches in other contexts (Ahmadi & Iswara, 2024; Giongo et al., 2020; Lidinillah et al., 2022). This finding suggests that

ethnomathematics—rather than remaining dependent on individual educators' initiatives and commitments—benefits from and indeed requires formal curricular structures, clear implementation guidance, and institutional policies recognizing and incentivizing cultural integration. Brazil's experience, wherein rigid national curricula constrained ethnomathematics innovation despite individual educators' willingness to innovate, illustrates that educational policy contexts function as critical constraints on implementation possibilities. These findings suggest that ethnomathematics scaling requires coordinated, multi-level intervention encompassing curriculum policy, teacher professional development, and resource development aligned with policy directives.

Ethnomodeling, technology, and knowledge bridging

Findings from RQ3 addressed how ethnomodeling practices and technology-enhanced tools supported connection between community-based and formal academic mathematics. Explicit ethnomodeling approaches—wherein community mathematical practices were systematically identified, represented, and abstracted toward formal mathematical concepts (Rosa & Orey, 2024)—demonstrated particular effectiveness in supporting students' mathematical reasoning and providing cognitive bridges between cultural familiarity and mathematical formalization (Desai et al., 2022). However, the finding that only 14 of 65 studies explicitly employed structured ethnomodeling, with an additional 8 studies demonstrating incomplete ethnomodeling sequences, indicates that ethnomodeling remains incompletely implemented and insufficiently theorized in contemporary ethnomathematics practice (Orey & Rosa, 2021). This gap represents a significant opportunity for future pedagogical development and research.

Technology-enhanced ethnomathematics expanded substantially post-pandemic, with 43% of corpus employing digital tools including digital modules, augmented reality, mobile platforms, and interactive simulations (Deda et al., 2024; Mumpuni & Marsigit, 2022). Technology demonstrated promise for expanding access to culturally contextualized learning, particularly for students in remote and resource-constrained contexts (Batiibwe, 2024, 2025). However, persistent digital divides—including unequal distribution of technology infrastructure, limited availability of culturally authentic resources in non-English languages, and risks of cultural decontextualization when technology was deployed without community partnership—substantially limited technology's transformative potential and actually exacerbated educational inequities in some contexts. This paradoxical finding—that technology simultaneously expands possibilities while reinforcing existing inequities—reflects fundamental tensions inherent in technology adoption within globally unequal educational systems.

Notably, evidence regarding long-term sustainability of technology-enhanced ethnomathematics remained limited, with longitudinal follow-up beyond 12 months documented in only 4 of 65 studies. This gap reflects a broader limitation of contemporary ethnomathematics research: insufficient attention to implementation sustainability and long-term impact. Given the substantial investments required for technology development and deployment, evidence regarding sustained impact and cost-effectiveness represents a critical

gap limiting practitioners' and policymakers' ability to make informed decisions regarding technology-enhanced ethnomathematics implementation.

Integration across dimensions: Toward a systemic understanding

The three research questions examined complementary dimensions of ethnomathematics—pedagogical effectiveness, implementation mechanisms, and technological affordances—yet findings suggest these dimensions are profoundly interconnected and cannot be understood in isolation. Pedagogical effectiveness depends fundamentally on implementation conditions including teacher preparation, curricular support, and resource availability (Kim, 2026). Furthermore, Lowell et al. (2024) stated that implementation dynamics are shaped by structural curricular frameworks and policy contexts that constrain or enable educator agency. Technology adoption is contingent on underlying pedagogical and implementation foundations and carries risks of cultural decontextualization absent appropriate theoretical grounding and community partnership (Mason et al., 2025). Conversely, strengthened professional development enhances pedagogical implementation fidelity and effectiveness; structured curricular frameworks facilitate consistent implementation and scaling; and technology, when appropriately designed and deployed with community input, can expand access while preserving cultural authenticity. This systemic interconnection suggests that effective ethnomathematics advancement requires coordinated intervention across multiple levels and domains rather than isolated focus on any single dimension.

Geographic and contextual variation: Implications for equity

This review's systematic examination of geographic variation in ethnomathematics implementation and research revealed profound disparities that carry significant implications for educational equity. Indonesia's robust ethnomathematics research base, structured implementation models, and relatively well-resourced professional development initiatives position that context as a leader in ethnomathematics implementation. Brazil's substantial research output exists in tension with structural curricular constraints limiting practical implementation. Thailand demonstrates emerging innovation with increasing institutional support, suggesting developmental trajectory toward systematic integration. However, Sub-Saharan African contexts (Zimbabwe and Nigeria) and Israel exhibit limited research output, ad hoc project-dependent implementation, and minimal institutional integration of ethnomathematics (Abubakar et al., 2021; Majadly & Amara, 2025; Mensah et al., 2025; Sharkia & Kohen, 2021). This geographic concentration of ethnomathematics research and implementation reflects broader patterns of educational research inequity wherein intellectual resources and innovation initiatives are concentrated in relatively affluent, politically stable regions while lower-income regions lack equivalent research infrastructure and policy support.

These geographic disparities carry direct implications for educational equity and cultural representation. Students in underrepresented regions—many of whom are culturally and linguistically diverse and have historically marginalized relationships with academic mathematics—lack access to the ethnomathematics research-based practices and resources that

could support their mathematical development and identity formation. The review's documentation that culturally authentic instructional materials and digital resources are disproportionately scarce in non-English, non-dominant language contexts further exacerbates this inequity, suggesting that ethnomathematics—while conceptually universal—remains practically inaccessible for many of the world's elementary students most likely to benefit from culturally responsive mathematics education.

Critical challenges and persistent gaps

Analysis across the three research questions identified recurring implementation barriers and critical research gaps that constrain ethnomathematics' scaling and effectiveness. Material scarcity—specifically, limited availability of culturally grounded, high-quality instructional resources—emerged as a consistent constraint across geographic regions, with particular severity in lower-income contexts wherein resource development depends on external funding and institutional capacity (Kaplan & Owings, 2022). On the other hands, Batiibwe (2025) explains that the absence of standardized, culturally valid assessment instruments measuring ethnomathematics learning outcomes hindered systematic evaluation and created accountability challenges for educators and administrators seeking to demonstrate impact. Therefore, curricular ambiguity and policy confusion regarding ethnomathematics integration created uncertainty at institutional and national levels, reducing administrative support and enabling consistent scaling.

Beyond implementation barriers, significant research gaps emerged. Longitudinal research examining sustained impact and long-term learning trajectories remained limited, with only a small subset of studies providing evidence beyond initial implementation periods. Cross-cultural comparative research systematically examining how ethnomathematics operates across distinct cultural contexts and educational systems remained sparse, limiting understanding of context-specific adaptation requirements and universal principles (Batiibwe, 2024; Deda et al., 2024; Nasrum et al., 2025). Research on artificial intelligence and immersive technologies for ethnomathematics remained preliminary and exploratory, with minimal empirical evidence regarding efficacy (Sunzuma & Umbara, 2025). The review's finding that qualitative research dominated (n = 31 studies) while quantitative studies remained limited (n = 18) suggests that while rich descriptions of ethnomathematics implementation mechanisms exist, rigorous quantitative evidence regarding comparative effectiveness and effect sizes remains constrained by measurement challenges and heterogeneous outcome definitions.

Implications for practice, policy, and research

The findings of this systematic review generate significant implications for practice, policy, and research in advancing culturally responsive elementary mathematics education. Collectively, the evidence underscores the necessity of positioning ethnomathematics as a systematic and theoretically grounded component of curriculum design, teacher preparation, and educational reform, rather than as a peripheral or additive approach.

For educators and curriculum developers, the documented positive effects of ethnomathematics on student achievement, engagement, and mathematical identity warrant its

deliberate and sustained integration into classroom practice. Such integration should move beyond superficial inclusion of cultural elements toward coherent alignment with formal mathematical objectives and disciplinary rigor (Aziz & Suprayitno, 2022; Batiibwe, 2024). Effective implementation requires the development of culturally grounded pedagogical content knowledge, particularly in relation to ethnomodeling as a bridge between community-based knowledge and formal mathematical representations (Bonney et al., 2026; Orey & Rosa, 2021). Moreover, collaboration with community knowledge holders and Indigenous experts is essential to ensure cultural authenticity, avoid tokenism, and support contextually meaningful learning experiences.

The review indicates that large-scale and equitable implementation of ethnomathematics is unlikely to be achieved through isolated classroom initiatives alone for policy. Instead, it requires coordinated policy support, including the establishment of formal curricular frameworks, sustained investment in teacher professional development, and the provision of high-quality instructional resources. Evidence from contexts such as Indonesia suggests that structured national strategies can facilitate more consistent implementation (Maarif et al., 2026). However, policy transfer must remain sensitive to local cultural, linguistic, and institutional conditions (Prahmana et al., 2026). In addition, policies addressing digital infrastructure and equity are critical to ensuring that technology-enhanced ethnomathematics expands access without reinforcing existing disparities, particularly through the development of culturally authentic and accessible digital resources.

The review also identifies several critical directions for future inquiry. Longitudinal research is needed to examine the sustained impact of ethnomathematics on students' learning trajectories, mathematical achievement, and identity development over time. Cross-cultural comparative studies would further elucidate how ethnomathematics principles are adapted across diverse sociocultural and institutional contexts, thereby distinguishing universal from context-specific factors influencing effectiveness (Turmuzi et al., 2024). The development and validation of culturally responsive assessment instruments remain an urgent priority to support rigorous evaluation and accountability (Prahmana et al., 2026). In addition, emerging research examining the role of artificial intelligence and immersive technologies in ethnomathematics learning—grounded in robust experimental or quasi-experimental designs—would extend current knowledge of technology integration (Putri et al., 2025). Finally, investigating the intersections between ethnomathematics and related equity-oriented frameworks, such as culturally sustaining pedagogy, social justice mathematics, and place-based education, would situate ethnomathematics within broader theoretical and practical discourses.

Across these domains, it is essential to recognize that the scaling of ethnomathematics necessitates contextually responsive adaptation. Consistent with sociocultural perspectives on learning, Prahmana et al. (2026) stated that mathematics education is inherently situated, culturally mediated, and socially constructed; therefore, both pedagogical practices and policy frameworks must be attuned to local knowledge systems and learner experiences. Furthermore, this review also offers a comprehensive and theoretically informed evidence base to guide educators, policymakers, and researchers in designing, implementing, and sustaining culturally responsive and technology-enhanced mathematics education. By elucidating the cognitive, affective, and sociocultural

mechanisms underpinning learning, it highlights the transformative potential of ethnomathematics when supported by coherent policy, robust teacher capacity, and culturally authentic resources.

Conclusion

This systematic review synthesizes 65 peer-reviewed empirical studies (2020–2025) to examine the implementation of ethnomathematics in elementary education across diverse global contexts. The analysis advances the field by organizing evidence along three interrelated dimensions: pedagogical approaches and learning outcomes, sociocultural mediational mechanisms and implementation conditions, and the integration of ethnomodeling with emerging technologies. Collectively, the findings position ethnomathematics as a theoretically coherent and empirically substantiated pedagogical orientation that supports mathematical achievement, reasoning, engagement, and identity development, particularly among culturally and linguistically diverse learners historically underserved by conventional instruction.

Across the reviewed studies, ethnomathematics-based instruction demonstrates consistent moderate-to-large effects on students' problem-solving and mathematical communication, with notable gains in geometry and numeracy. Importantly, these cognitive outcomes are accompanied by strengthened mathematical identities, increased engagement, and reduced mathematics anxiety, underscoring the multidimensional impact of culturally grounded instruction. Evidence from qualitative and mixed-methods studies further elucidates the sociocultural processes underlying these outcomes, lending empirical support to frameworks rooted in sociocultural constructivism, culturally responsive pedagogy, and ethnomodeling.

Notwithstanding these contributions, the review identifies persistent structural and epistemic constraints that limit scalability and equitable implementation. Teacher professional development remains uneven and insufficient, particularly with respect to ethnomodeling competencies and culturally grounded pedagogical content knowledge. The limited availability of culturally authentic instructional materials—especially in lower-income and non-English-speaking contexts—further constrains classroom practice. In addition, the absence of standardized, culturally valid assessment instruments impedes systematic evaluation of learning outcomes. These challenges are compounded by broader geographic inequities in research production and educational infrastructure. Although technology-enhanced ethnomathematics expands access and innovation, unresolved digital divides and risks of cultural decontextualization may inadvertently reproduce inequities without deliberate, context-sensitive design.

Addressing these challenges necessitates coordinated, multi-level action across policy, practice, and research. At the policy level, formal curricular recognition and structured implementation frameworks are required to institutionalize ethnomathematics within national education systems. Sustained investment in teacher professional learning—particularly in ethnomodeling and culturally responsive pedagogy—is essential to ensure instructional quality and long-term sustainability. The development of open-access, culturally responsive digital resources in multiple languages would further support equitable dissemination and adaptation. Future research should prioritize longitudinal and cross-cultural comparative designs to

examine sustained impacts, contextual variability, and the pedagogical implications of emerging technologies, including AI-supported learning environments.

Finally, the evidence affirms ethnomathematics as a viable pathway toward more equitable, culturally responsive, and pedagogically effective elementary mathematics education. Its transformative potential, however, is contingent upon the alignment of instructional innovation with systemic support, teacher capacity, and equitable resource distribution. A sustained, globally coordinated effort—grounded in cultural authenticity, community partnership, and methodological rigor—is therefore essential to ensure that ethnomathematics meaningfully expands opportunities for all learners to develop robust mathematical competencies and identities.

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Generative AI Statement	:	Generative AI tools, including NotebookLM, Perplexity, and Scopus AI, were utilized in a limited and supportive capacity to assist in preliminary idea development, identification of relevant literature, language refinement, and minor phrasing adjustments. These tools were not employed in the generation of substantive scholarly content. All aspects of the study's conceptualization, analytical processes, interpretation of findings, and synthesis of the literature were conducted independently by the authors and critically verified to ensure academic rigor, accuracy, and integrity.
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