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Ethnomathematics for sustainable and culturally responsive mathematics education in Ghana: An ethnographic exploration

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Abstract
Indigenous knowledge has long supported modelling and problem-solving within Ghanaian cultural contexts. This study examines cultural values and artefacts related to mathematics—ethnomathematics—that can make school mathematics more meaningful, realistic, and culturally responsive. The purpose of the study is to identify and describe ethnomathematics materials embedded in local cultural settings that can support mathematics educators and learners in understanding mathematical concepts through context-based modelling. Guided by a naturalistic paradigm, the study adopted a qualitative ethnographic design and used snowball sampling to engage five participants. Findings indicate that mathematics is embedded in everyday cultural practices and, when systematically integrated into curriculum and pedagogy, can strengthen learners' conceptual understanding, participation, and cultural identity. The study contributes practical insights for developing locally grounded teaching approaches by linking indigenous practices, symbols, and knowledge systems to mathematical modelling and classroom instruction. It further suggests that positioning ethnomathematics as a curriculum resource can support sustainable and equitable mathematics education by valuing local knowledge and improving cultural relevance across educational levels in Ghana.

Keywords: Culturally responsive pedagogy; Curriculum localization; Ethnomathematics; Indigenous; Mathematical modelling; Mathematics education; Sustainable education

1. Introduction

This paper begins by providing a background on the significance of integrating cultural artefacts and traditional practices into mathematics education, focusing on the Ghanaian context. It then explores the theoretical underpinnings of ethnomathematics and realistic mathematics education, highlighting how these approaches can transform teaching and learning experiences in culturally responsive and sustainable ways. The methodology employed in this study is discussed, emphasising the use of mathematical modelling to contextualise and deepen learners' understanding of mathematical concepts. Following this, practical applications of ethnomathematical modelling are presented, showcasing how local artefacts can be utilised to make mathematics more relevant and engaging for learners and to support inclusive participation. The paper searches for specific case studies and observations, illustrating the role of community practices and artefacts in fostering mathematical comprehension. Lastly, the paper discusses the findings and the implications for curriculum integration and long-term curriculum relevance. It concludes with recommendations for incorporating ethnomathematics into educational practices at all levels.

Recent enthusiasm for the maker movement (Peppler & Bender, 2013) provides a context for exploring how new activities can engage classroom learners in education. The maker movement uses technology, most frequently in non-formal educational contexts such as camps and after-school clubs, to engage learners directly with context and skills using a constructionist framework (Vossoughi & Bevan, 2014). In the context of digital transformation in education, such technology-enabled making can also extend into formal classrooms to support deeper, more contextualised learning. Integrating the Indigenous knowledge context of our people, which is typically excluded in school mathematics curriculum and mathematising, is also a noteworthy aspect of making meaning in ethnomathematics and mathematical modelling in education. Traditionally, people mould pots using clay into various geometric shapes, and learners are allowed to build models and find the area and volume of these models. This approach allows learners to mathematise real models into mathematical models, making mathematical modelling meaningful and realistic in mathematics education, especially in the Ghanaian context, where culturally grounded resources can support sustainable and equitable learning opportunities. However, such integration remains underrepresented in curriculum documentation and classroom resources from Basic schools through Senior High Schools to higher education. The gap this paper fills is the development of practical, innovative methods for integrating indigenous practices, symbols and knowledge systems into the study of mathematics, with implications for sustainable curriculum localisation. This contributes to the ongoing debates on ways of "decolonising knowledge." According to Sharma (2012), who argues that if our students only learn mathematics from an alien viewpoint, they might grow up to think that mathematics is not important to their culture, or worse, that the mathematics they learn in school is only for other people. This belief, which extends to "I cannot work with mathematics," may be dangerous for students of African cultural heritage. This could lead to students not seeing the beauty of mathematics and how mathematics is important across all disciplines in education. According to D'Ambrosio (1985), mathematics has been adapted and given a place as a scholarly practice known as "academic mathematics," which is taught and learned in schools. Ethnomathematics, on the other hand, is mathematics practiced among identifiable cultural groups, such as labour groups, national-tribal societies, and children at a particular age. This paper emphasises the transformative potential of mathematical modelling and culturally responsive teaching in mathematics education as a pathway toward sustainable education that values local knowledge and supports learner identity. The researcher's past engagement with diverse learner groups in a laboratory context aligned with the paper's focus on making mathematics meaningful through ethnomathematics and realistic modelling. This approach integrated cultural values into the mathematics curriculum by addressing cultural backgrounds and practical applications, enhancing learner engagement and reshaping their identities as mathematicians. This approach supported the paper's call to bridge perception gaps and foster inclusive, relevant mathematics education. Applications of ethnomathematical modelling in mathematics education builds on the study's methodology, informed by a naturalistic paradigm in mathematics education and rooted in ethnographic and sociocultural theory (Freudenthal, 1991; Gravemeijer, 2002; Moschkovich, 2019). The study explores the practical applications of ethnomathematical modelling. The methodological approach employed mathematical modelling to transform real-world contexts into mathematics and translate real-world problems into mathematical formulas (Erbas et al., 2014), and to analyse and organise underlying phenomena in real-life contexts. By demonstrating how these methods inform practical applications, this section highlights how integrating cultural artefacts and traditional practices deepens learners' understanding of mathematical concepts, making learning more meaningful, engaging, and relevant while supporting culturally sustaining classroom practices.

Working with diverse rural and urban learner groups through mathematical modelling provided deep insights into how cultural backgrounds, learning needs, and practical applications intersect in mathematics education (Asrizal et al., 2026; Bukari & Govender, 2024). Engaging with learners previously labelled as low-performing highlighted the potential of culturally relevant teaching to shift perceptions about learners' abilities and redefine educators' roles in fostering learners' mathematical identities in the classroom (Tofel-Grehl et al., 2017), thereby supporting inclusion and learner persistence—key concerns in sustainable education.

Understanding how the mathematisation of physical clay artefacts impacts learning or mathematising acts as the framing context for engaging in mathematical modelling moves in today's mathematics classroom. With ever-changing technology available to teach artefacts construction (mathematisation) (i.e., 3-D printers, laser cutters), opportunities for learners to learn while engaged in modelling and material manipulation (Halversion & Sheridan, 2014) can be expanded through digitally supported making and design-based learning, linking ethnomathematics to contemporary digital transformation agendas in education.

Clay Textile has been particularly effective in modelling traditional clay cultures' values while engaging learners in learning content standards. While technological options are ever-evolving, a recent interest in merging traditional clayey with modern technologies has expanded the maker movement in the past few years (Tofel-Grehl et al., 2017). Clay textiles (and related making practices) can be positioned as locally meaningful modelling contexts that bridge indigenous knowledge with contemporary tools, allowing learners to construct objects of personal value while tackling meaningful problems important to them in educationally empowering ways with contemporary technologies (Blikstein, 2013), and potentially enabling the development of reusable, locally grounded instructional resources.

In mathematics education, motivation and interest are highly correlated. Using activities that promote learner engagement while addressing learning standards is essential (Martin, 2015). Female engagement in mathematics activities is less than that of their male counterparts. Female learners report being less intimidated to engage in e-clay modelling-based learning due to the modelling elements of e-textile regardless of prior modelling experience with moulding (Kafai et al., 2014), suggesting that culturally meaningful and design-oriented tasks may contribute to more equitable participation. Beyond gender, clay moulding offers a valued space for ethnomathematics knowledge aspects in mathematics and modelling, supporting culturally responsive pedagogy and learner identity formation.

The literature highlights that cultural diversity may present challenges to integrating ethnomathematics into the teaching and learning of mathematics (Van der Walt et al., 2019). While this diversity is often seen as an obstacle, it can also foster a learning environment where learners are encouraged to explain mathematical concepts from their unique cultural perspectives (Mabotja, 2023). Ethnomathematics, mainly when applied through modelling, can empower 21st-century teachers with the tools and knowledge to teach mathematics differently from their schooling experiences (Mabotja, 2023), and can support sustainable curriculum renewal by embedding learning in locally available resources and practices. Importantly, Davidson (1992) asserts that teaching mathematics to learners from Indigenous cultures should prioritise real and concrete experiences over abstract and imaginary concepts. Ghanaian schools are not exempt from this consideration, as Davidson (1992, p. 243) notes that "abstract decontextualised teaching of mathematics has affected many American Indian learners' school success". Clivaz and Miyakawa (2020) conducted an international study comparing the effects of culture on mathematics teaching in Japan and Switzerland. In terms of problem solving in a lesson, considering pedagogy and discipline, the Japanese National Curriculum emphasizes learners' autonomous and independent learning. In Japanese problem-solving lessons, teachers discuss ideas rather than explicitly validating students' responses, as this is the responsibility of other learners. The learners in the session were familiar with this didactical construct, and only a handful requested that the teacher check their replies. In contrast, the Swiss teacher community shares the open problem and focuses on the problem-solving process rather than the outcome. This effect is evident in the Swiss mathematics textbook (Danalet et al., 1999), which contains just problem circumstances for numerous problems and no explicit concepts or ideas for students to acquire. The significant difference in this international comparative study between Japanese and Swiss highlighted cultural dispositions in mathematics classrooms, which is highly relevant to this study and related to how mathematical concepts are seen during the problem-solving process. Research studies on the exploration of ethnomathematics in structures (Fauzi et al., 2022; Zhang et al., 2021) observed that the Sasak people's architectural composition included trapezoids on the front, an isosceles triangle-shaped side roof, and a truncated pyramid-shaped stairway. Geometric ideas, such as the square, rectangle, and circle, can be found in the construction structure of the Temple of Heaven Edifice. Incorporating these cultural artefacts into Geometry and Trigonometry classes honours and confirms the community's indigenous knowledge and skills. This instils pride and ownership in learners (Kyeremeh et al., 2025). Geometric shapes in architectural works have a substantial impact on geometry instruction and assist ethnomathematics, which emphasises learning in real-world contexts by recognising learners' abundance of knowledge and abilities gained through lived experiences (Kyeremeh et al., 2025), reinforcing the argument that culturally grounded modelling can make mathematics more meaningful, realistic, and sustainable as a curriculum practice in Ghana.

1.1. Problem Statement

Despite extensive experience as a mathematics lecturer across Elementary, Junior High, Senior High school, College level, and now at the University, challenges commonly observed in rural educational institutions continued to hinder the effective teaching and learning of mathematics. In particular, these challenges include limited access to contextually appropriate learning resources, persistent learner disengagement, and inequities in learning opportunities across rural–urban settings, which raise sustainability concerns for mathematics education. As a mathematics lecturer and a researcher who has taught mathematics education for the past ten years to both Diploma and Bachelor of Education degree learners at the time the researcher was teaching at a College of Education in Ghana. The researcher's total teaching experience spanned 24 years, covering elementary through college level to the University. This extensive background highlighted the need for a more meaningful and realistic approach to mathematical modelling in mathematics education, mainly through integrating indigenous knowledge (ethnomathematics) to enhance learner motivation and interest. Such integration is positioned in this study as a pathway toward culturally responsive and sustainable mathematics education, where learning is grounded in locally available practices and resources. This approach aimed to bridge gaps in learners' understanding by making mathematical concepts relevant and engaging.

To address these challenges, the study aimed to visualise ethnomathematics materials available in the cultural settings that can help both mathematics educators and learners comprehend mathematical concepts from the context to mathematics. Specifically, it explored how meaningful and realistic ethnomathematics is in a Ghanaian context and its relevance to mathematics education, with the broader goal of informing sustainable curriculum localisation and inclusive participation in mathematics learning. Where relevant, the study also recognises that documenting and sharing local artefacts (e.g., through teacher-developed repositories or open educational resources) may support scalability and long-term use of culturally grounded materials across schools.

1.2. Research Question

To understand how clay modelling and other artefacts have affected changes in the cultural setting and its relevance to mathematics education, the researcher posits the following research question:

RQ 1) How meaningful and realistic is ethnomathematics in a Ghanaian context?

Understanding this research question provides insight into how clay moulding (modelling) as an ethnomathematics approach in various geometric shapes and vectors could engage learners in mathematical contexts. Furthermore, this understanding could shed some light on the role of teachers as facilitators, reflecting on their perceptions of their learners' capabilities and positionality in their community's indigenous knowledge and the mathematics classroom, and on how culturally grounded tasks may contribute to more equitable and sustainable learner engagement over time.

1.3. Background

Ethnomathematics explores the relationship between mathematics and culture, emphasising how different societies develop and use mathematical knowledge in practical and meaningful ways (D'Ambrosio, 1985; Rosa & Orey, 2013). In this study, ethnomathematics is conceptualised as a culturally sustaining pathway for improving mathematical comprehension by connecting formal concepts to learners' lived experiences, community practices, and locally valued artefacts. When learners encounter mathematics through familiar cultural forms—such as clay moulding patterns, market activities, indigenous architecture, and other everyday practices—mathematical ideas become less abstract and more intelligible, thereby supporting motivation and sustained participation in learning (Ladson-Billings, 2021; Vygotsky, 1978). This cultural relevance is not merely motivational; it contributes to sustainable learning by strengthening learners' sense of identity, belonging, and confidence in mathematics, particularly for those who may feel marginalised by decontextualised or alien curricular narratives (Furner & Duffy, 2022; Sharma, 2012).

In addition, ethnomathematics becomes educationally powerful when it is contextually authentic—that is, when it draws on real-world scenarios and artefacts from learners' communities and supports the process of mathematisation, where tangible cultural objects are transformed into mathematical representations and models (Freudenthal, 1991; Gravemeijer, 2002). In this sense, clay artefacts and other cultural objects can function as "real models" that learners translate into "mathematical models," enabling them to explore geometry, measurement, and vectors through modelling processes grounded in local practice. Beyond enhancing meaning-making, the use of locally available artefacts also provides a resource-sustainable approach for schools with limited access to commercial instructional materials, supporting curriculum localisation and the long-term viability of culturally responsive pedagogy.

For ethnomathematics to enhance comprehension rather than remain a peripheral cultural reference, it must also be conceptually rigorous, ensuring that mathematical depth is preserved while abstract ideas are made tangible (Rosa & Orey, 2013). Rigour, in this study, refers to maintaining explicit links between cultural forms and the underlying mathematical structures they instantiate (e.g., symmetry, transformations, spatial reasoning, proportionality, and vector composition), so that learners develop transferable conceptual understanding rather than isolated contextual familiarity. By recognising diverse mathematical traditions and positioning learners' cultural knowledge as legitimate intellectual capital, ethnomathematics can contribute to more inclusive learning environments that reduce mathematics anxiety and improve confidence (Furner & Duffy, 2022), thereby strengthening equity and supporting sustained engagement in mathematics learning pathways.

Finally, ethnomathematics is strengthened when enacted through culturally relevant pedagogy, where teaching prioritises active participation, hands-on modelling, storytelling, and community-rooted problem-solving (Ladson-Billings, 2021; Vygotsky, 1978). Ethnomodelling—linking ethnomathematics with mathematical modelling—offers a practical lens for this enactment by guiding teachers to structure tasks that begin with local practices and systematically develop formal mathematical reasoning (Erbas et al., 2014; Rosa & Orey, 2013;). Importantly, while ethnomathematics is anchored in the local, it also supports global inclusivity by enabling learners to compare mathematical practices across cultures and recognise mathematics as a universal human activity shaped by diverse historical and cultural developments (D'Ambrosio, 2006; Eglash, 1999). This dual orientation—locally grounded yet globally connected—aligns with sustainable education aims by strengthening cultural respect, social cohesion, and inclusive knowledge recognition, while supporting curriculum practices that remain meaningful and relevant over time.

By grounding mathematics in familiar and meaningful contexts, ethnomathematics helps learners see mathematics as a living, evolving discipline, not just abstract rules. This approach fosters deeper comprehension, engagement, and appreciation for both mathematics and cultural diversity, and supports curriculum sustainability by legitimising local knowledge as a reusable learning resource. Ethnomathematics philosophers in the past decades have shown interest in finding the most prudent way to facilitate Mathematics teaching and learning from a cultural perspective. This has been the concern of not only the governments of certain countries but also general stakeholders who have children's education at heart. Researchers investigate a lot on how to make mathematics education learning-friendly and teaching pleasant (Owusu-Darko et al., 2023). However, there remains a need for empirically grounded examples that translate ethnomathematics philosophy into concrete, curriculum-usable classroom materials and modelling tasks.

A new way researchers are looking at is to consider the teaching of mathematics in a cultural context. Ethnomathematical moves in teaching mathematical concepts have been considered in recent times to be one of the most efficient ways of teaching mathematics. Various theoretical discussions have been made about this philosophy (Peni, 2019). The practical aspect of this mathematical philosophy has not been considered so much (Owusu-Darko et al. 2023), especially from the Ghanaian perspective. In order to utilise the cultural know-how of the people and make mathematical concepts socially connected as the norms of culture demand, there is a need to consider Realistic Mathematics Education through ethnomathematics pedagogies (Purwanti et al., 2019; Sumirattana et al., 2017). The mathematical concepts in this study are limited to Geometric shapes and vector addition in a parallelogram because Geometry serves as a fundamental concept in ethnomathematics. After all, it is deeply embedded in various cultural practices and artefacts, making it a natural bridge between formal mathematical knowledge and learners' everyday experiences. Ethnomathematics incorporates contextual, cultural artefacts to provide learners with meaningful and relevant educational experiences. Culture can serve as a backdrop for studying mathematics (Zuya, 2017). This provides various benefits, including concept formation, access, and incentive to mathematics, modelling, and the provision of intellectual tools such as procedures, notations, and rules. Culture can serve as a context for learning, functioning as a source for application and for the development of specific skills in particular situations (Turmuzi et al., 2023). The ethnomathematics materials cover a wide range of topics, including plane, space, and transformational geometry, number patterns and operations, linear equations with one, two, and three variables, mathematical statistics, measurement, mathematical logic, congruence, similarities, Pythagorean theorem, vectors, comparisons, and fractions, among others. This study limited the concepts of ethnomathematics materials to geometry and vector addition in a parallelogram. The context is chosen because geometry content knowledge and conceptual understanding of ethnomathematics are found to be among the critical components for the integration of ethnomathematics approaches (Sunzuma & Maharaj, 2019). One significant drawback was the difficulty in obtaining indigenous specialists for interpreting the items and understanding how they were designed from the start, which also points to the importance of building institutional and community partnerships to support sustainable curriculum development and resource validation.

2. Method

2.1. Research Design

The study employed a research methodology informed by realistic mathematics education and sociocultural theory (Freudenthal, 1991; Gravemeijer, 2002). This approach used the indigenous knowledge system of modelling of artefacts, which could be represented in a mathematical context. By emphasising how the methods informed the real-world applications, this methodology facilitated the emergence of new relationships and a deeper understanding of mathematical concepts (Gravemeijer & Stephan, 2002).

This study employs an ethnographic approach, which includes artefact observation and unstructured interviews. It seeks a description and complete analysis of culture based on field research into how people organise and exhibit it (Nurjanah et al., 2021). Ethnography is concerned with discovering and explaining the structure of the human mind (Suherman, 2018). This study interprets natural phenomena by placing the researcher in a natural setting and observing indigenous people's daily lives, carefully watching what happens, listening to what is said, and asking questions that highlight the focus of the investigation. Ethnography is the description of culture, and its primary goal is to understand life through the eyes of indigenous people (Malinowski, 2014). Ethnography is distinguished by the complete participation of scientific research in investigating the culture of the society and the requirement of in-depth data collection (Zuya, 2017). This research takes a naturalistic philosophical viewpoint. A naturalistic paradigm is defined not by the methods utilised or the location where data is collected, but by a theoretical attitude and a set of research principles. The theoretical attitude argues that meaning is socially formed and negotiated in reality, and it employs various research principles such as considering multiple perspectives, examining cognition in context, and connecting theory generation and verification (Moschkovich, 2019).

2.2. Participants and Data Collection Process

Five indigenous specialists (three men and two women) participated in the study. The three male participants were senior community members aged 60 to 70 years and contributed extensive knowledge of Indigenous customs, knowledge systems, and the cultural uses of artefacts. Accessing these specialists required a snowball sampling approach: the researcher first contacted one participant, who referred him to another within the community, and this second participant subsequently directed the researcher to a third expert in a different settlement in Northern Ghana.

The two female participants, aged 30 to 50 years, were engaged through observation at a market centre where many artefacts were delivered for sale. During the market visit, the researcher observed that artefacts were frequently traded by individuals who sourced them from indigenous villages rather than producing them themselves. One woman indicated that she produced artefacts collaboratively with her mother, after which the researcher scheduled a community visit. As a result, the two women demonstrated their practical expertise in clay-based artefact modelling during the subsequent observation sessions.

Data collection combined observation and unstructured interviews. Observations were first conducted at the market centre to document a range of artefacts, followed by community-based observations focusing on the practical processes of modelling and artefact production. In addition, unstructured interviews were conducted with the indigenous specialists to (i) interpret the cultural meanings and uses of selected artefacts and (ii) confirm the cultural relevance of the ethnomathematics materials recorded in the researcher's field notes. Overall, the study relied on these observations and interviews to document ethnomathematics materials situated in everyday cultural practice and to support their interpretation as potential resources for modelling and curriculum integration.

2.3. Data Analysis Procedure

Data were analysed using an ethnographic analytic approach centred on systematic description, interpretation, and the presentation of culturally situated meanings. The analysis focused on comprehensively exploring the relationship between mathematical knowledge systems and culture by examining how mathematical conceptions are embedded in everyday practices and artefacts. Following widely used qualitative analysis steps outlined by Creswell, the researcher organised and prepared field notes and interview records, read through the dataset iteratively, and then identified and refined recurring patterns and meanings relevant to ethnomathematics and mathematical modelling. These patterns were used to generate interpretive accounts linking observed artefacts and participant explanations to curriculum-relevant mathematical concepts.

The analysis was informed by ethnographic methods in that it prioritised contextual interpretation of artefact use, including participants' explanations of cultural functions and meanings. In addition, evidence from prior research indicating that learners often experience increased interest and engagement when ethnomathematics is used in mathematics education (Verner et al., 2013) provided further justification for examining these culturally grounded materials as potentially meaningful resources in the Ghanaian context.

2.4. Ethical Considerations

All participants in this study were over the age of 18, and there was a low risk to them; thus, no ethical approval letter was required. All participants provided their informed consent to share information for data gathering. Overall, this study was executed ethically and transparently to eliminate any type of participant dishonesty. Informed consent guarantees that participants are completely informed of the risks, rewards, and processes involved, so safeguarding them from injury or exploitation.

3. Results

This section presents the key findings on how everyday cultural artefacts and indigenous modelling practices in Ghana can be mobilised as ethnomathematics resources to make school mathematics more meaningful and realistic. The findings show that mathematical ideas are embedded in ordinary objects, craftwork, and built environments, and that these cultural resources can be systematically connected to formal curriculum concepts through mathematisation and modelling. Across the dataset, four interrelated themes emerged, illustrating (i) where mathematical forms were observed, (ii) how modelling is enacted in cultural practice, (iii) how cultural meanings support curriculum relevance, and (iv) how artefacts can be translated into formal mathematical representations for concept formation.

3.1. Theme 1: Market Artefacts as Naturally Occurring Geometric Representations

As part of the researcher's visits to market centres, an observation was made on objects such as pumpkins and calabashes that are naturally designed with geometric shapes and can be used as ethnomathematics materials to make mathematics meaningful to learners. Samples of objects are seen in Figure 1.

Figure 1
Samples of clay models and calabash/pumpkins from a Ghanaian market

These market observations suggested that culturally familiar objects already embody geometric forms that can support classroom concept formation when treated as modelling resources (e.g., curved surfaces, symmetry, circles, and composite solids).

3.2. Theme 2: Community-based clay modelling as ethnomathematical modelling practice

There is a need to visualise ethnomathematics materials available in the cultural settings that could help both teachers and learners comprehend mathematical concepts. To emphasise the need for this, the researcher also visited a community and observed how ladies use clay to model various shapes of pots and bowls for everyday and cultural purposes, as seen in Figure 2. Figure 3 shows completed clay modelling products.

The ladies applied geometric knowledge in constructing a circle as the base for most of their artefacts because they are commonly used in the communities. The researcher asked one of them to model in the shape of a rectangle, and Figure 2 illustrates the start of the modelling work. Due to time constraints, it was not completed before we left. The idea was that you could ask for any design, and they could use their indigenous knowledge to model it exactly for you. These observations indicate that clay modelling functions as an authentic modelling environment in which geometric reasoning is embedded in practice (e.g., establishing bases, shaping curvature, maintaining proportionality, and approximating symmetry). This indigenous knowledge used in

Figure 2
Modelling of clay into bowls and pots

Figure 3
Completed clay modelling products

the communities within Ghana is not done by elderly people alone, but their children, in formal education, take part in this cultural activity. This continuity across generations further supports the “realistic” dimension of ethnomathematics, insofar as learners encounter these artefacts and practices within everyday community life.

The Indigenous people not only model objects but also apply the modelling on the walls of their Indigenous homes, known as “Rondavel houses,” where tessellations are applied. These are mathematical concepts that could be related to the classroom for learners to understand mathematical concepts clearly. Across observations and participants’ explanations, practical making (clay artefacts) and built environments (indigenous homes and wall patterns) consistently emerged as culturally situated resources that can be linked to geometry and measurement topics in the formal curriculum.

Participants framed the curriculum potential of these practices in terms of valuing Indigenous knowledge systems within formal schooling, describing such integration as a way of recognising locally situated expertise and broadening what counts as legitimate mathematical knowledge. This framing was reflected in their emphasis on connecting community practices (e.g., clay modelling and patterned wall designs) to school topics such as geometry, tessellations, and measurement.

3.3. Theme 3: Indigenous Specialists' Interpretations Confirm Cultural Functions and Curriculum Relevance

This section explores how ethnomathematical approaches can integrate local cultural artefacts into mathematics education. By connecting mathematical concepts to tangible objects rooted in learners' cultural contexts, this approach seeks to make learning more relevant and engaging. Using artefacts like traditional clay models, storage vessels, and architectural designs demonstrates how mathematical modelling and ethnomathematics can deepen learners' comprehension of geometry, measurement, and other mathematical concepts. Table 1 highlights various local artefacts and their potential applications in the mathematics curriculum. Each artefact is associated with specific school levels and mathematical concepts, showing how they can be used as tools for learning.

Local artefacts for ethnomathematics and modelling

Cultural artefacts	*Mathematics curriculum for the school level*	*Basic concepts of ethnomathematics and modelling in cultural perspective*	*Mathematical concept formation*
Figure 4 *Hunting artefacts* 	Senior high school and Colleges of Education	Measurement of finger length and arm. Modelling of a cylindrical-shaped object for storing arrows with a bow used in hunting wild animals in the forest and for war dances during funerals for people who request particular gravestones (**interviewee response**)	Measurement of length and distance, curved area of a cylinder, lines, line segments, and rays (Euclidean geometry) and Vector addition (parallelogram)
Figure 5 *Men's Traditional Underwear termed "lebre"* 	Basic schools (primary and junior high) and senior high schools	Modelling of indigenous triangular underwear for traditional land owners and great men for war dances during funerals and soothsaying in the Northern parts of Ghana (**Interviewee response**)	Lengths and area of a triangle.
Figure 6 *A traditional storage artefact called "zaalinga"* 	Senior high schools	Modelling of half-opened calabashes arranged cylindrically and supported with a net of rope as a storage device for unique ingredients such as dry guinea fowl, dry okro, dry dawadawa, local salt called "neere" to prepare meals for funeral rites and also for special visitors from the Northern parts of Ghana (**interviewee response**)	Area of a semi-circle and various types of geometric shapes in the net of ropes.

Table 1 continued

Cultural artefacts	*Mathematics curriculum for school-level*	*Basic concepts of ethnomathematics and modelling in cultural perspective*	*Mathematical concept formation*
Figure 7 *Indigenous traditional home* 	Senior high schools	Geometric shapes building homes of indigenous people from the Northern parts of Ghana	Area of dimensions, volume of the building, total areas of geometric shapes
Figure 8 *Modern traditional home* 	Senior high schools	Geometric shapes of the building of modern homes are derived from indigenous perspectives in the Northern parts of Ghana.	Areas of shapes from the base of the building to the apex with dimensions can be calculated, the volume of the building, the total surface area of the building, etc.

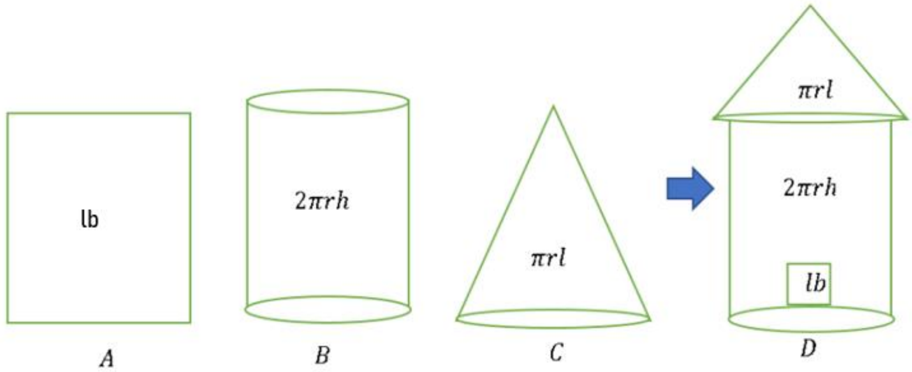
Table 1 demonstrates how these artefacts serve as meaningful and culturally relevant tools for teaching mathematical concepts, bridging the gap between abstract theory and practical, real-world applications. Table 1 presents a detailed overview of cultural artefacts and their connection to ethnomathematics, modelling, and concept formation. In particular, the specialists' explanations linked artefacts to concrete cultural practices (e.g., hunting, storage, funerary rites, and home construction), which in turn provided contextually grounded entry points to mathematical concepts such as measurement, area, surface area, and spatial reasoning. For instance, one senior participant explained the cultural purpose of a storage artefact and the way it is assembled in practice: "This storage piece is used to keep dried ingredients for funeral rites and special visitors. We arrange the calabashes and secure them with a rope net so they can hold many items" (M1). Similarly, clay modelling was described not only as craftwork but as a structured making process that depends on geometric reasoning: "When we start a pot, we first make the base round. If the base is not balanced, the whole shape will not stand well" (F2). These interpretive accounts anchored the artefact-to-curriculum mapping in lived cultural functions rather than treating artefacts as decontextualised instructional objects. This theme also clarifies the methodological contribution of the interviews: rather than treating artefacts as neutral "objects," the specialists' interpretations positioned them as culturally meaningful practices, thereby strengthening the credibility of the artefact-to-curriculum mapping presented in Table 1.

3.4. Theme 4: From Artefacts to Mathematisation Pathways and Concept Formation

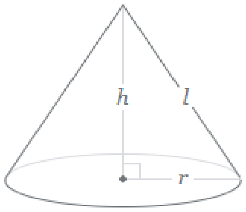
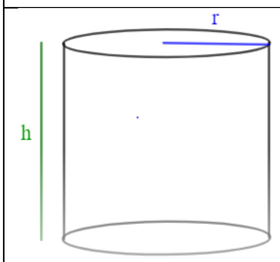
To answer the research question—How meaningful and realistic is ethnomathematics in a Ghanaian context?—the details in Table 1 and the concept formation in Figures 9 and 10 address the meaningful and realistic aspects of ethnomathematics in a Ghanaian context, which could enhance learners' concept development in mathematics. The learners would understand that the indigenous home they live in is full of mathematical applications and ideas, and this would make mathematical concepts easy to comprehend and not seen in abstract form. In other words, "meaningfulness" is evidenced by the cultural familiarity and interpretive significance of the artefacts, while “realism” is evidenced by their availability in local settings and their direct alignment with formal curriculum topics through mathematisation.

Using Figures 7 and 8, indigenous and modern traditional homes can be represented mathematically for senior high school learners, applying the principles of mathematisation and realistic mathematics education. As illustrated, these models use geometric shapes in ethnomathematics to calculate and explore areas, dimensions, and related properties (Figure 9).

Figure 9
Connecting ethnomathematics to mathematical concept formation



These representations demonstrate a modelling pathway from a real cultural structure to formal mathematical quantities (e.g., floor area, outer surface area, and volume), supporting curriculum links to geometry and measurement. The essential information and formulae to calculate the floor area, outer surface area, and volume of Figure 7 are the following.

	*Volume of the conical thatch roof* $V = \frac{1}{3}\pi r^2 h$ Surface area (inner or outer) of the Fig 7 (conical) roof: $A = \pi r(r + \sqrt{h^2 + r^2})$ or $A = \pi r\sqrt{h^2 + r^2}$?
	*Volume within the cylindrical wall* $V = \pi r^2 h$ Surface area of the (inner or outer) curved wall: $A = 2\pi rh + 2(2\pi r^2)$ or $A = 2\pi rh + \frac{1}{2}(2\pi r^2)$ Area of the floor: $A = \pi r^2$

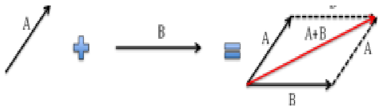
Similarly, using Figure 4, learners can be taught Euclidean geometry concerning lines, line segments and rays.

	A line segment is part of a line with starting and endpoints.
	A line is an endless straight path at both ends.
	A ray has a starting point but has no endpoint.

The hunting artefacts (bow and arrows, in Figure 4), where the "arrows" are mathematically represented as rays, could be combined to form a parallelogram in vector addition as shown in Figure 10.

Figure 10

Rays used as vector addition in a Parallelogram



It can be noted through the diagram in Figure 10 that the operation is commutative:

$\vec{A} + \vec{B} = \vec{B} + \vec{A}$ This demonstrates that vectors can be added using the head and tail method. Here, the artefact does not merely "illustrate" mathematics; rather, it becomes a culturally grounded representation that enables learners to construct and justify a formal mathematical procedure through modelling.

Building on this modelling logic, the artefact can be used not only to demonstrate a procedure but also to structure learners' active mathematisation and justification of mathematical ideas. Learners can be asked to do the activities below:

Example Activity 1: Lines, segments, rays

(i) Study Figure 4 and identify one line, one line segment, and two rays.

(ii) Explain (in one sentence each) why your selections match the definitions of a line, a segment, and a ray.

(iii) Sketch the same objects using standard geometric notation (arrows/endpoints).

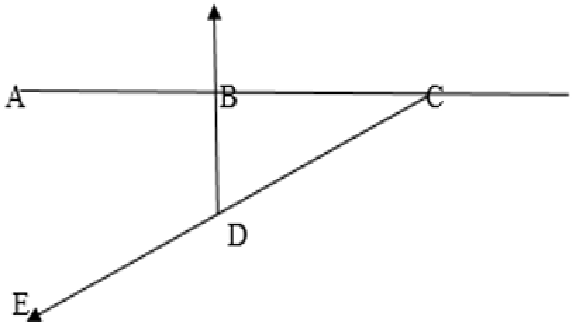


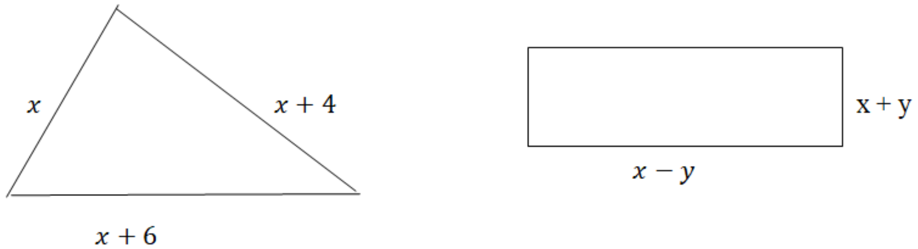
Figure 5 about the triangle of traditional underwear could be used to teach the perimeter of a triangle. Figure 7 could be used to find the perimeter of a rectangular object at the elementary level, especially in Grade 5, as illustrated in the learner instruction below:

Example Activity 2: Perimeter (Algebraic Expressions)

(i) Write the perimeter expression for each shape by adding all side lengths shown (use brackets where necessary).

(ii) Simplify each expression by collecting like terms (e.g., $x+x+(x+6)+(x+6)\rightarrow 4x+12$)

(iii) Explain your reasoning in one or two sentences, stating how you identified which sides are equal (e.g., opposite sides of a rectangle are equal) and why perimeter is found by summing all sides.



Example Activity 3: Vector addition with parallelogram

(i) Using Figure 10, draw vectors $\vec{A}$ and $\vec{B}$ from a common tail and complete the parallelogram.

(ii) Label the resultant vector $\vec{R}$ and write the relationship $\vec{R} = \vec{A} + \vec{B}$.

(iii) Repeat the construction by swapping the order and state what you observe about commutativity.

Taken together, these examples illustrate a consistent mathematisation pathway: culturally familiar artefacts provide concrete referents that can be translated into formal representations (diagrams, measurements, symbolic expressions) and then used to support concept formation and procedural justification in school mathematics. This supports the claim that ethnomathematics is both meaningful (culturally anchored) and realistic (locally available and curriculum-linkable) in the Ghanaian context.

4. Discussion

This study sought to raise awareness of how everyday cultural artefacts and indigenous modelling practices can function as meaningful and realistic resources for the development of mathematical concepts in the school system, particularly within the Ghanaian context. Drawing on observational ethnography of market artefacts (e.g., calabashes and pumpkins), community-based clay modelling, and indigenous specialists' interpretations, the findings collectively show that mathematical ideas are not confined to formal school texts but are embedded in ordinary objects, craftwork, and built environments. When these resources are systematically connected to formal curriculum concepts through mathematisation and modelling, they offer a culturally situated pathway for strengthening conceptual understanding and learner engagement. This contribution addresses the gap identified in the literature regarding the need for practical, innovative approaches that integrate indigenous practices, symbols, and knowledge systems into the teaching and learning of mathematical concepts in ways that are usable within classrooms and curriculum materials.

A key implication of the findings is that ethnomathematics can counter the perception of mathematics as a "foreign" discipline by positioning it as a culturally recognisable human activity. This aligns with Sharma's (2012) argument that when learners encounter mathematics primarily from an "alien viewpoint," they may conclude that mathematics is disconnected from their culture and, consequently, disengage from learning. In contrast, participants in this study expressed pride in the wealth of indigenous knowledge and its connection to mathematics, suggesting that cultural validation can be pedagogically consequential for learners' motivation and willingness to participate. Using artefacts from their communities, learners can connect with reality, culture, and nature (D'Ambrosio, 2018), transforming traditional, teacher-centred practices (Gerdes, 1994) into innovative and culturally resonant approaches. Such insights resonate with Owens' (2012) advocacy for integrating indigenous knowledge through community partnerships, where learning is strengthened through collaboration with elders and specialists. Owens et al. (2011) further conceptualise this approach as a form of democratic education grounded in indigenous rights, respect, and self-determination—an orientation that is especially relevant for sustainable education agendas that prioritise inclusion, equity, and culturally responsive schooling.

The artefact-to-concept mapping presented in Table 1 deepens this argument by showing how cultural meanings and functions provide contextually grounded entry points to formal mathematical ideas such as measurement, area, surface area, and spatial reasoning. Rather than treating artefacts as decontextualised "objects," the specialists' interpretations framed them as culturally meaningful practices (e.g., storage for community rites, hunting artefacts, traditional clothing, and housing forms). This interpretive anchoring strengthens the credibility of using ethnomathematics as a curriculum resource because the mathematical modelling is not imposed externally but emerges from culturally situated use and meaning. In this regard, the findings corroborate evidence that learners tend to respond positively to ethnomathematics-based instruction (Verner et al., 2013) and support the broader claim that culturally grounded contexts can make mathematics more engaging and educationally consequential (Astuti et al., 2024; Owusu-

Darko et al., 2023).

The modelling examples also demonstrate how ethnomathematics can support concept formation through explicit mathematisation pathways. The connection between Figures 7–9 illustrates how indigenous and modern traditional homes can be translated into formal representations that support geometry and measurement outcomes (e.g., floor area, outer surface area, and volume). This aligns with prior studies that document ethnomathematical structures embedded in buildings and architecture as powerful contexts for learning (Fauzi et al., 2022; Zhang et al., 2021). Similarly, the connection between Figures 4–10 illustrates how culturally familiar artefacts can support procedural justification and conceptual clarity: arrows, interpreted as rays, can be modelled to build a parallelogram structure for vector addition, including commutativity, consistent with established representations of vector addition procedures (Chang, 2013). Importantly, this modelling logic supports Zuya's (2017) argument that conceptual understanding is evidenced when learners can justify why a rule holds or where a mathematical procedure originates. By locating formal procedures in culturally meaningful referents, ethnomathematical modelling may strengthen both "knowing how" and "knowing why," thereby supporting deeper comprehension.

Beyond learner outcomes, the findings also highlight implications for teacher competence and professional knowledge. If ethnomathematics is to be integrated effectively, teachers must possess sufficient content knowledge, procedural fluency, and pedagogical knowledge to guide mathematisation without reducing cultural artefacts to superficial "decorations." As Zuya (2017) notes, a strong grasp of mathematical concepts and procedures contributes to teacher confidence and supports the diagnosis of learner difficulties and misconceptions. In practice, this suggests that teacher education and professional development should not only encourage culturally responsive pedagogy but also support teachers in designing modelling tasks that preserve mathematical rigour while remaining culturally authentic. Such capacity-building is particularly important if the goal is curriculum integration "from foundational stages to higher education," as advocated in this study.

The discussion also connects directly to debates on decolonising knowledge and curriculum legitimacy. In this paper, "decolonising knowledge" is understood as the critical process of dismantling the dominance of Eurocentric and colonial frameworks in education and research while centring Indigenous and marginalised knowledge systems as equally valid and valuable. This orientation challenges assumptions that Western epistemologies are universally superior and instead supports pluralistic, culturally rooted ways of knowing and learning. In the Ghanaian context, the findings suggest that when educators and learners reflect on cultural heritage and relate community practices to classroom mathematics, it may (a) enable the sharing of indigenous knowledge in relation to specific mathematics topics (e.g., geometry, tessellations, vectors), (b) foreground relationships and connectedness as foundations for learning, (c) legitimise ethnomathematics and related indigenous methodologies as appropriate pedagogical approaches across educational levels, and (d) inform institutional ethics and protocols concerning indigenous research and community participation. This is consistent with Owens' (2012) emphasis on partnerships with elders and the educational value of outdoor/community learning as a respectful and mutually beneficial knowledge exchange.

Finally, the study reinforces the feasibility and educational value of integrating ethnomathematics into mathematics education. As prior work suggests, ethnomathematics can help learners connect mathematics to everyday life and integrate mathematical principles with local culture (Kusuma et al., 2018; Owens, 2012; Zhang & Zhang, 2010). The present findings extend this argument by showing concrete Ghanaian examples—market artefacts, clay modelling practices, and culturally meaningful structures—alongside curriculum-relevant mappings (Table 1) and mathematisation demonstrations (Figures 7–10). Within the aims of sustainable education, these results support curriculum localisation as a pathway for improving relevance, participation, and cultural affirmation, while also suggesting practical directions for curriculum developers and teacher educators seeking to institutionalise culturally grounded modelling as a regular feature of mathematics teaching rather than an occasional enrichment activity.

5. Conclusion

Mathematics becomes more meaningful and realistic when educators move beyond decontextualised instruction and employ culturally grounded ethnomathematics and mathematical modelling that connect school concepts to learners' lived experiences. The artefacts synthesised in Table 1 demonstrate how locally familiar cultural resources—such as clay modelling products, storage vessels, hunting artefacts, and indigenous and modern home structures—can function as context-rich entry points for developing curriculum-aligned concepts in geometry, measurement, and vectors. By making explicit pathways from cultural contexts to formal mathematical representations (e.g., the modelling links illustrated across Figures 7–10), this conceptual study underscores how mathematisation can bridge abstract theory and practical application in ways that are intelligible and motivating for learners in the Ghanaian context.

The study affirms that mathematics is embedded in everyday cultural practices and that its systematic integration into curriculum and pedagogy can strengthen learners' conceptual understanding and participation. In doing so, the study contributes practical and innovative examples that address a documented gap in the field: the need for workable strategies and materials that integrate indigenous practices, symbols, and knowledge systems into mathematics education. From a sustainable education perspective, such curriculum localisation can support more inclusive and equitable learning by validating learners' cultural identities, leveraging locally available resources, and improving the long-term relevance of mathematics learning across diverse communities. Therefore, within the framework of Ghana's curriculum, the study recommends that ethnomathematics and modelling be incorporated as a structured pedagogical approach across educational levels—from foundational schooling through teacher education and higher education—supported by teacher professional development and curriculum resources that preserve mathematical rigour while remaining culturally authentic.

Data availability: Upon reasonable request, the corresponding author will provide the datasets created and/or analysed during the current work.

Declaration of interest: The authors declare no competing financial or personal interests in this paper.

Ethical declaration: Because all participants in this study were over the age of 18, no ethical approval letter was required. Participants were given informed consent forms before observation and the taking of pictures for the research work.

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