



Reconceptualizing ethnomathematical knowledge: A recursive framework of culture, practice, cognition, and mathematization

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Abstract: Ethnomathematics still lacks integrative theoretical models. To help fill this gap, this article proposes the Culture–Practice–Cognition–Mathematization (CPCM) framework as a culturally grounded approach for interpreting ethnomathematical knowledge. The framework conceptualizes ethnomathematical knowledge as a decentralized system of relations among culture, practice, cognition, and mathematization, shifting attention from the identification of isolated mathematical elements toward the processes through which knowledge is constituted, transmitted, and transformed within culturally situated activities. Culture is understood as the epistemological ground that shapes the meaning and legitimacy of knowledge; practice as the domain in which knowledge is enacted; cognition as the process through which knowledge is interpreted and generalized; and mathematization as the process through which relationships become represented, modelled, and systematized. Rather than treating mathematization as a final stage leading toward formal mathematics, the framework views it as one dimension within a broader system of knowledge formation. The explanatory potential of the framework is illustrated through an analytical vignette of the Mongolian ger. The CPCM framework can be used to examine ethnomathematical knowledge in many cultural contexts and may guide future empirical and educational research.

Keywords: *Ethnomathematics, culture, mathematical practice, cognition, mathematization, conceptual framework*

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INTRODUCTION

Over the past several decades, ethnomathematics has developed at the intersection of mathematics education, anthropology, and cultural studies, establishing itself as a key field for examining mathematical knowledge within sociocultural contexts. The field has challenged the view of mathematics as a universal, culture-free logical system, emphasizing instead how mathematical ideas (such as: number, measurement, spatial organization, and pattern), emerge, acquire meaning, and are transmitted and used within diverse cultural practices (D'Ambrosio, 1985, 1990).



As the body of scholarship in the field has grown, recent reviews and edited volumes have noted that ethnomathematics has developed along multiple lines, including philosophical–epistemological inquiry, practice-centered ethnography, situated cognition, mathematization and modelling, and critical social perspectives (Orey & Rosa, 2021; Batiibwe, 2024). Bibliometric studies have likewise indicated a marked increase in ethnomathematics publications and the emergence of multiple thematic clusters over the past decade, which shows how diverse the field has become and how far its methods and theories have matured (Rusli & Safaah, 2023; Deda et al., 2024; Turmuzi et al., 2024; Nasrum et al., 2025).

While this multidimensional development has enriched the theoretical possibilities for interpreting ethnomathematical knowledge, it also suggests that a unified analytic language capable of systematically explaining the relationships among the commonly used foundational concepts of culture, practice, cognition, and mathematization remains relatively underdeveloped (Skovsmose, 2022; Nicol et al., 2024). This leaves room for understanding ethnomathematical knowledge not as an isolated “cultural example” or merely an expression of practice but rather as a set of mutually conditioning, recursive, and nonlinear processes across these four dimensions.

Despite the rich body of ethnomathematics research, existing studies remain largely fragmented across cultural, practical, cognitive, and modeling perspectives. A comprehensive theoretical account that systematically integrates these dimensions as mutually conditioned processes is still lacking. This article addresses this gap by proposing a culturally grounded recursive conceptual framework that reconceptualizes ethnomathematical knowledge as a dynamic system rather than a collection of isolated cultural examples.

This conceptual study makes three contributions to ethnomathematics research. First, it reconceptualizes ethnomathematical knowledge as a recursive system of mutual conditioning among culture, practice, cognition, and mathematization, shifting attention from isolated examples to the processes through which ethnomathematical knowledge is generated, transformed, and sustained. Second, it provides a culturally grounded analytical framework that enables systematic comparisons across diverse cultural contexts. Third, it offers implications for culturally responsive mathematics education by reframing culture as an epistemological condition of knowledge formation rather than a supplementary context.

Theoretical Foundations and Epistemological Orientations of Ethnomathematics

The theoretical foundations of ethnomathematics begin with an epistemological stance that critically reinterprets the traditional view of mathematics as a universal, culture-free logical structure. D'Ambrosio (1985) laid the foundation for this orientation by defining mathematics as a complex of techniques, practices, and explanations developed within particular cultural settings, thereby establishing a theoretical basis for understanding mathematical knowledge as inseparable from history, language, values, and ways of life. This position marked an important shift, relocating the basic question of “what counts as mathematical knowledge?” from universal criteria to cultural frames.

Developing this epistemological orientation further, Bishop (1988) showed that mathematical activities found across all cultures; such as counting, measuring, locating, designing, playing, and explaining; do not share a single identical logical structure, but instead manifest differently according to the needs, meanings, and forms of organization of particular cultures. Consequently, ethnomathematics expanded beyond merely documenting examples from “other” cultures and became a theoretical field for explaining the plurality of epistemological forms of mathematical knowledge.

Barton (1996), working within the theoretical scope of ethnomathematics, raised the meta-level question of “what counts as ethnomathematics?” and emphasized the need not to privilege culture, practice, cognition, or mathematization in isolation, but to explain their interrelationships. For him, ethnomathematics is not a fixed object with a stable definition; rather, it is a theoretical problem concerned with how knowledge is constituted, used, and rendered meaningful. This approach is important because it helps ethnomathematics avoid the risk of becoming trapped in essentialist notions of “cultural uniqueness.”

A common feature of these foundational works is that they treat culture not as an external context of mathematical knowledge but as its epistemological basis. However, these works tended to leave the relations among culture, practice, cognition, and mathematization at the level of principle, leaving later studies to develop these dimensions more fully.

Ethnomathematics Grounded in Culture and Practice

In ethnomathematics research, practice is understood not merely as the context in which mathematical ideas are “applied,” but as the primary domain in which mathematical knowledge emerges and stabilizes. Gerdes (1992, 1996) showed that

traditional crafts, architecture, ornamentation, games, and other social practices contain mathematical structures in an implicit form, even when they have not been formalized. In his work, mathematical ideas appear not as externally imposed formal systems but as knowledge embedded in practice.

Ascher (1991) treated cultural practices not as aggregates of isolated techniques, but as systems with internal logic, rules, and organization, thereby broadening the analytic possibilities for examining practice within ethnomathematics. Similarly, Zaslavsky (1973) described everyday calculation, trade, games, and measurement as “living mathematics,” regarding mathematical thinking in cultural practice as an autonomous form of knowledge distinct from formal school mathematics.

Powell and Frankenstein (1997) further interpreted practice not simply as an everyday activity but as a cultural field linked to power, social organization, and educational policy. From this perspective, practice becomes a crucial site for understanding how mathematical knowledge is transmitted, legitimized, and institutionalized. Decolonial studies have similarly viewed practice as a space of both epistemic colonization and resistance, deepening the practice-centred orientation of ethnomathematics. Although these studies clearly establish practice as a fundamental component of ethnomathematical knowledge, they also suggest that practice has often been examined primarily within cultural interpretation without fully exploiting the possibility of systematically linking it to cognition and mathematization.

Cognition and Situated Mathematical Thinking

In ethnomathematics research, cognition has generally been understood not as an internal and universal process of individual thought, but as a situated process that emerges through participation in culturally meaningful practice. Lave and Wenger (1991) described learning as a situated practice, showing that knowledge develops within collective contexts through participation in an actual activity. Hutchins (1995) further expanded the theoretical foundations of cognition in ethnomathematics by conceptualizing cognition as being distributed across systems of people, tools, environments, and collective organizations.

Saxe (1991) examined how numbers, measurements, and ratios are understood and used within cultural practices, demonstrating that cognitive structures stabilize through repeated activities in practice. The culturally grounded mathematical activities identified by Bishop (1988) can likewise be understood as cognitive patterns through such processes of internalization.

Nemirovsky and Ferrara (2009) showed that mathematical concepts emerge through the coordinated interplay between representation, movement, and interaction, thereby creating possibilities for a more fine-grained study of the multiple channels involved in cognitive processes. More recently, Radford (2017, 2020) interpreted mathematical cognition as embodied and semiotic, emphasizing the importance of bodily movement, gestures, and the material environment in the constitution of mathematical meaning.

Although these cognition-focused studies underscore the importance of practice and culture, they also reveal that a theoretical language capable of systematically connecting cognition to mathematization remains relatively underdeveloped.

Mathematization and Abstraction: Nonlinear Approaches

In ethnomathematics research, mathematization has increasingly been interpreted not as a one-way final stage in which traditional knowledge is translated into formal mathematical language, but as an analytic process through which practice- and cognition-based knowledge is reorganized at another level. Gerdes (1996) argued that mathematical structure already exists within traditional practices and that the task of the researcher is to reveal and clarify it. This position makes it possible to understand mathematization not as a replacement for cultural knowledge but as a means of articulating its internal logic.

Barton (1996, 2008) emphasized that abstraction in ethnomathematics must remain meaningful and coherent with the logic of culture, practice, and cognition. For him, mathematization should not be carried out arbitrarily by the researcher; it must also “work” from the standpoint of the participants.

Skovsmose (2023) described mathematization as a nonlinear, recursive, and multidirectional process within critical mathematics education, showing how mathematical models can feed back into practice. The educational studies by Stillman et al. (2013, 2017) support this view by demonstrating that mathematical modelling and mathematization are multiple and context-dependent processes.

Together, these approaches allow mathematization to be understood not as the inevitable final stage of ethnomathematical knowledge but as a linking process that keeps change moving through the culture–practice–cognition system.

The Problem of Integration and the Theoretical Space

Ethnomathematics has been developed through a rich theoretical tradition in which culture, practice, cognition, and mathematization have each been examined in depth. At the same time, these lines of inquiry have often evolved in parallel and remain focused on their own analytic questions, creating difficulties in explaining ethnomathematical knowledge as a unified process.

In cultural studies, meaning, symbolism, and normative frameworks tend to predominate; in practice-centred research, sequences of action and material environments are foregrounded; cognition studies emphasize internalization, embodiment, and distributed processes; and mathematization studies focus on abstraction, modelling, and systematization. Although these differences in emphasis reflect the richness and diversity of ethnomathematics research, they also indicate that a common analytical framework for integrating these dimensions as parts of a mutually conditioning process remains insufficiently developed.

This opens up room for understanding ethnomathematical knowledge not as a “cultural example,” a “practical activity,” or an “alternative mathematics” in isolation, but as a nonlinear system of recursive relations among culture, practice, cognition, and mathematization. This space does not reject the achievements of previous studies but instead points to the need for a conceptual framework that can integrate, compare, and systematically interpret them.

Table 1. Positioning the CPCM Framework in Relation to Major Ethnomathematics Approaches

Framework	Primary analytical focus	Relatively less developed dimension(s)	Distinctive contribution of CPCM
Ethnomodelling (Orey & Rosa, 2021)	Translation and dialogue between cultural mathematical practices and academic mathematics	Cognitive mechanisms linking practice and mathematical representation are often implicit	Makes cognition an explicit analytical component connecting practice and mathematization
Sociocultural theory (Lave & Wenger, 1991; Hutchins, 1995)	Participation, situated learning, and distributed cognition within social activity	Processes of mathematization and mathematical abstraction receive less explicit attention	Integrates cognition with mathematization as mutually conditioning processes

Framework	Primary analytical focus	Relatively less developed dimension(s)	Distinctive contribution of CPCM
Critical mathematics education (Skovsmose, 2022, 2023; Powell & Frankenstein, 1997)	Power relations, social justice, critique, and the sociopolitical role of mathematics	Recursive relations among culture, practice, cognition, and mathematization are not the primary analytical concern	Provides a system-level perspective linking cultural meaning, activity, cognition, and mathematical representation
CPCM Framework (present study)	Recursive relations among culture, practice, cognition, and mathematization	Requires further empirical operationalization and validation across diverse cultural contexts	Offers an integrative analytical framework for examining ethnomathematical knowledge as a dynamic and mutually conditioned system

While these perspectives have significantly advanced ethnomathematics research, they tend to privilege particular dimensions; cultural meaning, practical activity, cognitive processes, or mathematization; rather than recursive interrelations. Consequently, ethnomathematical knowledge is often interpreted through single-dimensional lenses, limiting the possibility of understanding it as a dynamic system-level phenomenon. The framework proposed in this article builds on these contributions but shifts the analytical focus to the mutually conditioned relations among culture, practice, cognition, and mathematization, conceptualizing them as components of a nonlinear and culturally grounded system.

Although these theoretical traditions have significantly advanced ethnomathematics research, they tend to foreground different aspects of the relationship between culture and mathematics. Ethnomodelling emphasizes the translation and dialogue between cultural and academic mathematical knowledge, sociocultural approaches focus on participation and situated learning, while critical mathematics education highlights issues of power, critique, and social transformation. Building upon these contributions, the Culture–Practice–Cognition–Mathematization (CPCM) framework proposes a more integrative perspective by focusing on the recursive relations among cultural meanings, social practices, cognitive processes, and mathematical representations. Table 1 positions the proposed framework in relation to these major ethnomathematics approaches and clarifies its distinctive analytical contribution.

As shown in [Table 1](#), the CPCM framework is not intended to replace existing approaches in ethnomathematics. Rather, it seeks to complement them by drawing analytical attention to the recursive interactions among culture, practice, cognition, and mathematization. While each tradition offers important insights into particular dimensions of ethnomathematical knowledge, the CPCM framework emphasizes how these dimensions mutually shape and transform one another within culturally situated systems of activity. Its contribution, then, is not a new area of inquiry but a way of examining existing areas in relation to one another.

METHODS

This study is a conceptual literature review aimed at theory building rather than an empirical investigation; therefore, no primary data were collected. Its purpose was to synthesize existing ethnomathematics scholarship into an integrative framework explaining the relationships among culture, practice, cognition, and mathematization. The review proceeded in three stages. First, foundational works that established the epistemological basis of the field (e.g., D'Ambrosio, [1985](#), [1990](#); Bishop, [1988](#); Barton, [1996](#)) were identified and used as theoretical anchors. Second, the corpus was extended to recent reviews and empirical studies. Sources were included when they addressed ethnomathematical knowledge or culturally situated mathematical thinking and offered conceptual, theoretical, or empirical insight into at least one of the four dimensions or their interrelations. Third, the selected literature was analyzed through thematic synthesis: each source was examined for how it conceptualized and related the four dimensions of CPCM, and recurring patterns and gaps were compared across sources. These insights informed the construction of the recursive framework presented in the Results and Discussion section, which is then illustrated through the case of the Mongolian ger. To enhance transparency and reduce selection bias, all sources informing the analysis are cited explicitly in the text and listed in the References.

RESULTS AND DISCUSSION

The proposed framework comprises four interrelated components that shape ethnomathematical knowledge: culture, practice, cognition, and mathematization. Rather than representing sequential stages through which knowledge develops, these components function as complementary analytical dimensions that coexist, interact, and recursively influence one another. The framework therefore seeks to explain not individual elements in isolation, but the dynamic relations through which

ethnomathematical knowledge is constituted, maintained, transformed, and reinterpreted.

Table 2 summarizes the conceptual structure of the framework. For each component, the table identifies its theoretical grounding and substantive content. Theoretical grounding refers to the principal conceptual traditions that inform the interpretation of each component, whereas content refers to the key forms, processes, and phenomena associated with that dimension. Together, these four components give researchers a shared vocabulary for examining ethnomathematical knowledge in different cultural contexts. Each component is discussed below.

Conceptual Orientation and Guiding Principles

The proposed framework is not intended to classify, evaluate, or prescribe ethnomathematical knowledge. Nor does it function as a methodological protocol for data collection or analysis. Rather, it is offered as an integrative analytical perspective through which ethnomathematical phenomena may be interpreted, connected, and compared across different cultural settings.

The framework is guided by three principles. First, it is culturally grounded. Culture is understood not as an external context surrounding mathematical knowledge, but as the condition that shapes what forms of knowledge are considered meaningful, useful, and legitimate. In this sense, culture provides the interpretive horizon within which ethnomathematical knowledge emerges and acquires significance.

Second, the framework is conceptual rather than empirical. Its purpose is not to explain a single cultural practice, but to clarify the relations among four analytical dimensions: culture, practice, cognition, and mathematization; and to bring them into a common interpretive perspective. This orientation supports theoretical comparison across diverse ethnomathematical cases.

Third, the framework adopts a recursive perspective. Rather than assuming a one-way progression from culture to practice or from practice to mathematics, it views ethnomathematical knowledge as an ongoing process in which the four dimensions continually influence one another. This perspective provides a basis for examining how ethnomathematical knowledge is generated, maintained, and transformed over time.

Core Components of the Framework

The proposed framework comprises four analytical dimensions: culture, practice, cognition, and mathematization. Together, these dimensions provide a common vocabulary for examining how ethnomathematical knowledge is organized, interpreted,

and expressed across diverse cultural contexts.

Table 2 summarizes the conceptual structure of the framework. For each dimension, the table identifies its theoretical grounding and substantive content. Theoretical grounding refers to the principal conceptual traditions informing the interpretation of each dimension, whereas content refers to the key processes, forms, and phenomena associated with it.

Table 2. Conceptual Structure of the CPCM Framework

Component	Theoretical grounding	Content
Culture	The epistemological ground that gives meaning to and legitimizes knowledge (D’Ambrosio, 1985, 1990; Bishop, 1988; Barton, 1996)	Values, symbols, normative concepts, linguistic categories, and fields of meaning related to mathematics
Practice	The system of activity in which knowledge emerges and stabilizes (Gerdes, 1992, 1996; Ascher, 1991; Zaslavsky, 1973; Powell & Frankenstein, 1997)	Recurrent sequences of action, decision-making criteria, and organization of the material environment
Cognition	Situated, embodied, and distributed cognition (Bishop, 1988; Lave & Wenger, 1991; Hutchins, 1995; Saxe, 1991; Radford, 2017)	Internal rules, orientation, representation, and generalization
Mathematization	An analytic process that reorganizes practical knowledge at another level (Gerdes, 1996; Barton, 1996, 2008; Skovsmose, 2023; Stillman et al., 2013, 2017)	Representation, ratio, model, abstraction, and systematization

The following elaborates each dimension and clarifies its contribution to the overall framework. Issues concerning the empirical application and operationalization of these dimensions are discussed separately.

Culture

Within the proposed framework, culture is understood as the epistemological ground that gives meaning to and legitimizes knowledge. Rather than serving merely as a social background or contextual setting, culture provides the values, symbols, linguistic categories, and normative assumptions through which mathematical activity becomes intelligible within a particular community.

At the cultural level, communities define what kinds of problems are worth addressing, what forms of explanation are considered acceptable, and which ways of reasoning are regarded as meaningful. Culture therefore shapes not only the content of knowledge but also the criteria by which knowledge is recognized, transmitted, and

evaluated. From this perspective, ethnomathematical knowledge cannot be fully understood without examining the cultural meanings that sustain and organize it.

Culture is not treated as a static collection of traditions or as a marker of cultural uniqueness. Rather, it is understood as an evolving system of meanings that both shapes and is shaped by human activity. Within the framework, culture provides the symbolic and normative conditions through which ethnomathematical knowledge emerges and acquires significance.

Practice

Practice refers to the system of socially meaningful and recurrent activities through which knowledge is enacted, maintained, and reproduced within a cultural context. Within the proposed framework, practice is not understood simply as the application of pre-existing knowledge, but as the domain of activity in which knowledge emerges, acquires stability, and becomes embedded in everyday life.

The content of practice includes recurrent sequences of action, decision-making criteria, and the organization of the material environment. Such practices may involve measuring, comparing, estimating, constructing, navigating, allocating resources, or coordinating collective activities. Although participants may not describe these activities in formal mathematical terms, they often embody regularities, procedures, and forms of reasoning that contribute to the development and transmission of ethnomathematical knowledge.

From this perspective, practice constitutes the activity-based dimension of the framework. Ethnomathematical knowledge becomes visible, is enacted, and is sustained as community members take part in socially organized activities.

Cognition

Cognition refers to the processes through which knowledge enacted in practice becomes organized as interpretation, representation, orientation, and generalization. Within the proposed framework, cognition is not understood as an isolated mental activity located solely within the individual mind. Rather, it is viewed as a situated, embodied, and distributed process that develops through participation in culturally organized practices and interactions with people, artifacts, and environments.

At the cognitive level, recurrent patterns of action and decision-making become stabilized as internal rules, orientations, and representational structures. Individuals learn not only how to perform particular activities, but also how to recognize relevant relationships, interpret situations, and anticipate appropriate responses. Through repeated

engagement in practice, knowledge becomes generalized beyond specific situations, allowing familiar patterns of reasoning to be applied in new contexts.

From this perspective, cognition constitutes the interpretive dimension of the framework. It provides the representational resources through which ethnomathematical knowledge can be understood, generalized, and communicated across situations.

Mathematization

Mathematization refers to the process through which knowledge grounded in culture, practice, and cognition is reorganized and expressed in forms that make relationships more explicit, communicable, and analytically accessible. Within the proposed framework, mathematization is not understood as the translation of cultural knowledge into formal academic mathematics. Rather, it is viewed as a process through which patterns, structures, and relationships become represented, compared, modelled, abstracted, and systematized.

The content of mathematization includes representation, ratio, model, abstraction, and systematization. Through representation, practical knowledge becomes visible in diagrams, symbols, classifications, or other forms. Through comparison and ratio, relationships among quantities, objects, or actions become more explicit. Models provide simplified structures that make complex practices understandable, while abstraction enables knowledge to be generalized beyond particular situations. Systematization organizes these insights into coherent structures that support communication, reflection, and further development.

From this perspective, mathematization constitutes the analytical dimension of the framework. It provides the means through which ethnomathematical knowledge can be represented, examined, communicated, and further developed across contexts.

Recursive Relations and the Conceptual Model

In the proposed framework, culture, practice, cognition, and mathematization do not form a linear sequence or one-way causal chain. Rather, they constitute a recursive system in which each dimension both influences and is influenced by the others. Change may originate in any component and generate consequences across the wider system.

For example, a new form of mathematization, such as a representation, model, or classification, may reorganize practice, reshape cognitive orientations, and eventually contribute to new cultural interpretations of knowledge. Conversely, changes in cultural meanings and values may redirect practice, stimulate new forms of reasoning, and

generate alternative forms of mathematization. The framework therefore emphasizes relations among components rather than privileging any single dimension as the primary source of ethnomathematical knowledge.

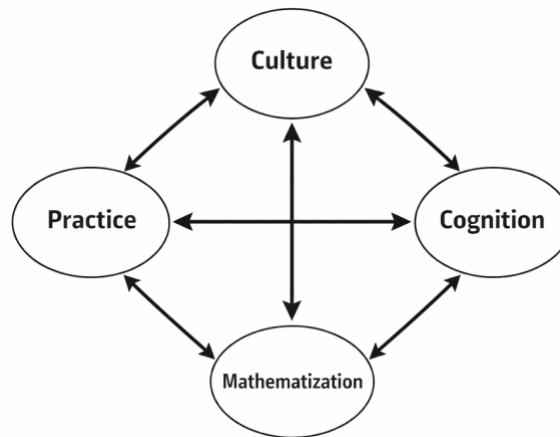


Figure 1. Proposed conceptual model of ethnomathematics

Figure 1 represents this perspective through a decentralized conceptual model in which culture, practice, cognition, and mathematization occupy equal analytical positions and are connected through reciprocal relationships. Ethnomathematical knowledge is thus understood not as a fixed body of cultural content but as an ongoing process that is continuously produced, maintained, transformed, and reinterpreted through interactions among these dimensions.

Seen this way, the framework gives researchers a shared language for examining how ethnomathematical knowledge operates across different cultural settings. Rather than treating ethnomathematical phenomena as isolated examples, it offers a basis for interpreting and comparing ethnographic cases, oral traditions, and practice-based educational experiences through a shared conceptual structure.

Operationalizing the Framework

Although the proposed framework is primarily conceptual, it is intended to support empirical inquiry by providing a structure for examining ethnomathematical phenomena across multiple dimensions. Rather than prescribing a fixed methodology, it offers a flexible analytical perspective that may be applied in qualitative, quantitative, or mixed-methods research.

Table 3. Illustrative Analytical Questions, Evidence Sources, and Analytical Foci for Applying the CPCM Framework

Component	Guiding analytical question	Possible evidence sources	Analytical focus (coding focus)	Expected analytical insight
Culture	What counts as meaningful, legitimate, or valuable knowledge within this cultural context?	Interviews, narratives, myths, rituals, linguistic categories, cultural documents	Legitimacy, symbolism, values, normative meanings, cultural classifications	Identification of cultural meanings, values, and legitimacy structures
Practice	What recurrent activities, routines, or interactions organize and stabilize knowledge?	Participant observation, field notes, activity sequences, artifacts, tools	Routines, coordination patterns, decision criteria, procedural organization	Understanding of how knowledge is enacted and maintained in practice
Cognition	How do participants perceive, represent, interpret, and generalize knowledge?	Think-aloud protocols, drawings, explanations, collaborative problem-solving, multimodal interactions	Representations, orientations, generalizations, reasoning patterns	Identification of cognitive representations, orientations, and reasoning patterns
Mathematization	How is knowledge expressed, modeled, abstracted, or systematized through mathematical forms?	Diagrams, classifications, models, quantitative representations, participant explanations	Abstraction, modelling, formalization, systematization, feedback into practice	Understanding of mathematical structures, representations, and abstraction processes

Researchers may enter the framework through any of its four dimensions: culture, practice, cognition, or mathematization; and examine how each relates to the others within a particular ethnomathematical context. The purpose is not simply to identify mathematical elements embedded in cultural practices, but to investigate how knowledge is organized, interpreted, communicated, and transformed across interconnected dimensions.

Table 3 operationalizes the framework by presenting illustrative analytical questions, possible sources of evidence, analytical foci, and expected insights associated with each dimension. The table is intended as a heuristic guide rather than a prescriptive protocol, allowing researchers to adapt the framework to diverse cultural contexts and methodological traditions.

The analytical foci presented in **Table 3** should be understood as flexible coding categories rather than fixed procedures. Depending on the research design, researchers may adapt, combine, or refine these categories to examine how culture, practice, cognition, and mathematization become empirically visible within particular ethnomathematical settings.

Implications

This section considers the implications of the proposed framework for ethnomathematics research and mathematics education. Rather than functioning as a methodological protocol, the framework provides an analytical perspective for examining how culture, practice, cognition, and mathematization interact in the production and development of ethnomathematical knowledge.

The framework does not reject the descriptive and example-centered traditions of ethnomathematics research. Instead, it seeks to situate particular cases within a broader analytical structure that highlights relations among cultural meanings, practical activities, cognitive processes, and forms of mathematization. In this way, ethnomathematical examples become points of entry for examining wider processes of knowledge formation and transformation.

It has been discussed that the implications of this perspective for ethnomathematics research include its potential for comparative analysis and theory development. The implications for mathematics education, particularly the repositioning of culture as a condition for the formation of mathematical knowledge, have shown significance. The section then illustrates the application of the framework through an analytical vignette of the Mongolian *ger*. Although the *ger* serves as the primary example, the discussion also considers its potential relevance for interpreting other ethnomathematical contexts, including Mongolian shagai games, African fractal settlement patterns, Polynesian navigation systems, Japanese sangaku traditions, Indonesian batik designs, and Brazilian street-vending mathematics.

Implications for Ethnomathematics Research

The proposed CPCM framework offers several theoretical contributions to ethnomathematics research. Rather than rejecting the example-centered and descriptive traditions of the field, it provides an analytical perspective through which individual cases may be connected, compared, and interpreted within a common conceptual structure. While previous studies have documented mathematical elements embedded in cultural practices and everyday activities (Gerdes, 1996; Powell & Frankenstein, 1997), the relations among culture, practice, cognition, and mathematization have often remained implicit. The proposed framework makes these relations analytically visible.

First, the framework broadens the kinds of questions that may be asked in ethnomathematics research. Rather than focusing only on what mathematics can be identified within a cultural practice, researchers may also ask how knowledge is culturally legitimized, enacted through practice, represented cognitively, and expressed through processes of mathematization (Bishop, 1988; Skovsmose, 2023). This shift supports more process-oriented and multilevel analyses of ethnomathematical knowledge.

Second, the framework strengthens the analytical role of qualitative research. Observation, interviews, ethnography, and participatory methods remain essential for examining cultural meanings, practices, and cognitive processes. However, the framework provides a common structure through which different forms of qualitative evidence may be interpreted in relation to one another, supporting theoretically informed analyses rather than isolated descriptions (D'Ambrosio, 2006; Rosa & Orey, 2016; Stillman, 2019).

Third, the framework supports critical orientations that recognize the epistemological legitimacy of culturally grounded knowledge. Rather than evaluating knowledge solely according to the standards of formal Western mathematics, it encourages researchers to examine knowledge within its own cultural logic, purposes, and domains of use. In this way, ethnomathematical knowledge can be understood not as an incomplete version of formal mathematics, but as one among multiple legitimate forms of knowing (Orey & Rosa, 2021; Skovsmose, 2022; Nicol et al., 2024).

In summary, the framework provides a basis for comparing and interpreting ethnomathematical knowledge across diverse cultural settings. Such comparisons are grounded not in similarities among artifacts, but in patterns of relations among culture, practice, cognition, and mathematization

Implications for Mathematics Education

The proposed framework has several implications for mathematics education. By understanding culture, practice, cognition, and mathematization as interconnected dimensions of knowledge formation, it provides a basis for reconsidering curriculum design, teaching, and learning from a culturally grounded perspective.

First, the framework supports the development of curricula that recognize local knowledge as a source of mathematical understanding rather than merely as a collection of illustrative examples. Culture is viewed not as an external context added to mathematics, but as a condition that shapes what counts as meaningful knowledge and how mathematical ideas emerge within lived experience (Bishop, 1988; Rosa & Orey, 2016).

Second, the framework strengthens the theoretical basis of culturally responsive mathematics education. Students' everyday experiences and practice-based knowledge can be understood as resources for learning rather than as obstacles to formal mathematics. In this way, culturally grounded experiences become bridges through which mathematical understanding may be developed (Bartell et al., 2017; Hunter & Hunter, 2024).

Third, the framework encourages a broader understanding of mathematization. Rather than treating formalization as a single end point, it recognizes multiple pathways through which learners may represent, explain, and organize knowledge. Diagrams, visual models, embodied actions, verbal explanations, and symbolic representations may all function as legitimate forms of mathematical expression (Rosa & Orey, 2016; Stillman, 2019).

Fourth, the framework has implications for teacher education. It encourages teachers to view students' cultural experiences and practical knowledge as interpretive resources within instruction. This perspective shifts teaching from the transmission of content toward the mediation of meaning and the design of learning environments that are culturally responsive and cognitively flexible (Bartell et al., 2017; Hunter & Civil, 2021).

Overall, the framework treats culture as a foundation of mathematical knowledge rather than an add-on to instruction. This, in turn, can help make mathematics education more inclusive, meaningful, and responsive to diverse ways of knowing.

Illustrative Vignette: The Mongolian Ger

To show how the CPCM framework works in practice, this section examines the Mongolian *Ger*. The purpose is not to present the *Ger* as a unique model of ethnomathematics, but to illustrate how the framework can be used to examine relations among cultural meanings, practical activities, cognitive processes, and forms of mathematization within a concrete activity system (Barton, 2008; Stillman et al., 2017). The *Ger* is selected because spatial

organization, material structure, collective activity, and cultural meaning are simultaneously observable within its construction and use.

Erecting a *Ger* is not the execution of a detailed predesigned plan but a process of coordinated adjustment grounded in collective experience. The lattice wall is expanded into a circular form, the door is positioned according to traditional orientation, the crown ring (toono) is raised, and roof poles (uni) are inserted while participants continuously assess the structure through visual and bodily cues. Decisions concerning wall expansion, column placement, and rope tension are made through shared judgment rather than formal measurement. Stability emerges through interaction among people, materials, and culturally informed practices, illustrating how practical knowledge is enacted and coordinated within everyday activity (Byambajav, 2025). The principal structural elements are shown in Figure 2.

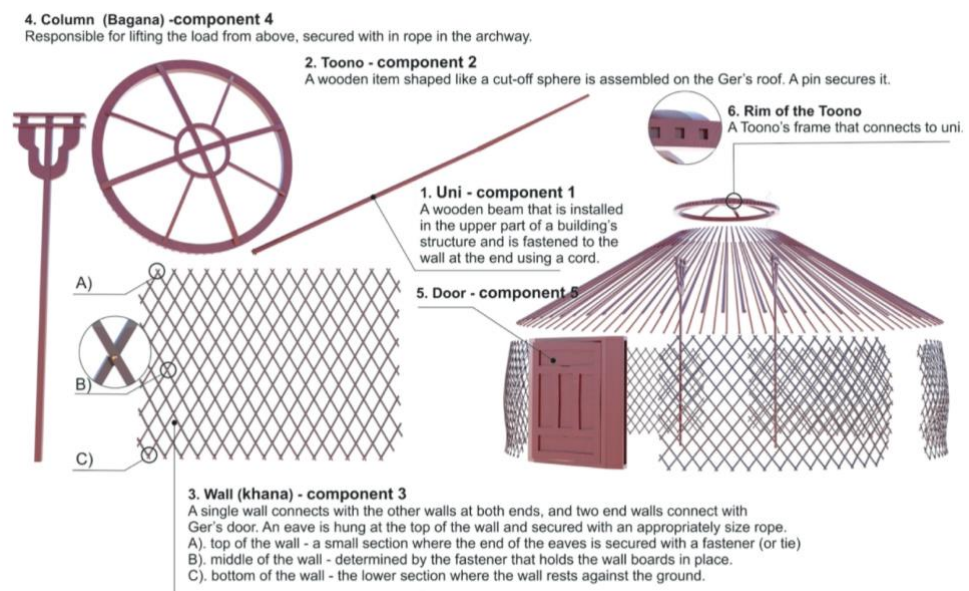


Figure 2. The components of the Mongolian *Ger* (uni—component 1, toono—component 2, wall—component 3, column—component 4, door—component 5)
(Byambajav, 2025—used with the author's permission)

Figure 2 presents the principal structural elements of the Mongolian *Ger*, while Table 4 examines how knowledge associated with these elements may be interpreted through the dimensions of culture, practice, cognition, and mathematization. Rather than viewing the ger solely as an architectural structure, the framework lets us see it as a knowledge system in which cultural meanings, practical activities, cognitive orientations, and forms of mathematization are intertwined. This analysis illustrates how the framework can reveal relations among dimensions that are often examined separately in ethnomathematics research.

Table 4. Analytic application of the framework to the Mongolian *Ger*

Component	Evidence in <i>Ger</i> construction	What this level explains	What remains unexplained without other levels
Culture	South-facing door; sacred khoimor; symbolic association of toono with the sky	Defines what counts as a “proper” form and spatial organization; legitimizes orientations	Does not explain how the structure is physically achieved or stabilized
Practice	Sequential actions: unfolding lattice, raising toono, inserting uni, tensioning ropes	Shows how balance and symmetry emerge through coordinated activity	Does not explain why these forms are meaningful or how knowledge transfers
Cognition	Visual-tactile judgments (“too steep,” “even”); embodied coordination; distributed knowledge	Explains how practitioners perceive, evaluate, and adjust structure in real time	Does not explain cultural legitimacy or abstract structural relations
Mathematization	Radial symmetry; proportional relations; network modeling of lattice wall	Makes structural relations explicit and comparable across contexts	Does not account for lived meaning or practical enactment

Table 4 shows that no single dimension can adequately explain *Ger* construction; its ethnomathematical significance emerges through relations among culture, practice, cognition, and mathematization. The radial organization of the *Ger* expresses both spatial symmetry and structural interdependence, providing an analytical basis for understanding how balance and form are achieved in practice.

Culture. At the cultural level, erecting a *Ger* unfolds within a field of meanings that defines what counts as a proper and socially legitimate form. Developed through centuries of nomadic life, the *Ger* embodies social organization, worldviews, customs, and symbolic associations (Badamkhatan et al., 1987; Baatarkhuu & Odsuren, 2015). Spatial features such as the south-facing door, the privileged position of the khoimor, and the symbolic association of the toono with the sky organize the dwelling according to culturally recognized orientations. Consequently, judgments such as “even” or “properly set” express culturally meaningful criteria rather than purely geometric ones, illustrating how ethnomathematical knowledge is embedded within systems of value and symbolism (D’Ambrosio, 1990).

Practice. At the practical level, *Ger* construction constitutes a stabilized system of coordinated actions. Expanding the wall, raising the toono, inserting the uni, and balancing the tension ropes follow established sequences and decision criteria even in the absence of formal measurement (Baatarkhuu & Odsuren, 2015; Gerdes, 1996). Through repetition, this organization becomes an implicit procedural logic embedded in practice and transmitted across generations (Badamkhatan et al., 1987; Ascher, 1991).

Cognition. Cognitively, the knowledge involved in *Ger* construction is situated, embodied, and distributed. Participants evaluate angles, alignment, and stability through visual perception, tactile feedback, material resistance, and accumulated experience. Repeated engagement stabilizes these judgments as internalized orientations that guide action (Hutchins, 1995; Saxe, 1991). Because construction is collective, knowledge is distributed across participants rather than located in any single individual. Thus, cognition consolidates practical orientations into transferable understandings that support interpretation and coordination (Radford, 2017).

Mathematization. At the level of mathematization, the *Ger* can be represented as a system of spatial relations in which the toono functions as a central node, the uni as radiating elements, and the lattice wall as the boundary defining the overall form. This configuration lends itself to geometric interpretation in terms of symmetry, proportion, and relational dependence (Tsovoovadavaa et al., 2018). Recent studies have modelled the lattice wall as a network structure and described the *Ger* through parameterized geometry, highlighting the flexible yet stable properties of the woven framework (Byambajav, 2025). Such representations put experiential knowledge into analytical terms and make it easier to compare across contexts.

However, formal representations do not replace practical knowledge. Stability is achieved through actions such as adjusting and balancing rather than through measurement alone, while mathematical interpretation articulates these orientations at a more general level (Barton, 2008; Stillman et al., 2017). Mathematization therefore repositions knowledge within another analytical coordinate system and may influence subsequent practice through education, design, and standardization (Skovsmose, 2023).

This feedback process can be observed in contemporary representations of the *Ger*. Architectural drawings, digital modelling, and educational materials increasingly describe the *Ger* through geometric and structural concepts. These mathematized representations do not merely document existing practices; they also influence how the *Ger* is taught, reconstructed, and understood by new generations. In this way, mathematization feeds back into cognition, practice, and cultural interpretation, illustrating the recursive character of ethnomathematical

knowledge.

Overall, the *Ger* illustrates that ethnomathematical knowledge cannot be reduced to cultural symbolism or structural description alone. Rather, it emerges through relations among cultural meanings, coordinated practice, embodied cognition, and processes of mathematization. This example does not represent all regional or historical variations and may diverge from participants' own interpretations; it should therefore be understood as an analytical illustration rather than an empirical proof of the framework's validity.

Although the Mongolian *Ger* serves as an illustrative example, the framework is not limited to architectural forms of cultural knowledge. Similar analyses may be conducted in diverse ethnomathematical contexts, including Mongolian shagai games (Miyejav & Otgonbaatar, 2025), African fractal settlement patterns (Eglash, 1999), Polynesian navigation systems (Barton, 1996), Japanese sangaku traditions (Rothman & Fukagawa, 1998), Indonesian batik designs (Permita et al., 2022), and Brazilian street-vending mathematics (Carraher et al., 1985). These cases suggest the broader applicability of the framework across diverse ethnomathematical domains while maintaining its focus on relations among culture, practice, cognition, and mathematization.

This article makes three principal contributions to ethnomathematics research. First, it proposes the CPCM framework as an integrative analytical structure for examining ethnomathematical knowledge. While previous traditions have generated important insights into cultural knowledge, social practice, mathematization, and critical perspectives, these dimensions have often been examined separately. The CPCM framework brings them into a common analytical perspective, enabling ethnomathematical phenomena to be interpreted through their relations rather than as isolated cultural examples.

Second, the framework explicitly incorporates cognition as a distinct analytical dimension. Although cognitive processes are frequently implied in studies of cultural practices and mathematical activity, they have often remained theoretically underdeveloped within ethnomathematics research. By foregrounding cognition, the framework provides a clearer account of how knowledge is interpreted, represented, generalized, and communicated across contexts.

Third, the article advances methodological development by outlining an initial pathway for operationalizing the framework. Through the use of analytical questions, evidence sources, and coding foci, the framework moves beyond conceptual description and provides a basis for future empirical, comparative, and interdisciplinary investigations of ethnomathematical knowledge. In short, the CPCM framework is meant

to complement existing approaches, not replace them, by supporting more systematic analysis of relations among culture, practice, cognition, and mathematization.

Several limitations of the proposed framework should be acknowledged. First, the framework remains primarily conceptual and has not yet been systematically validated across multiple cultural settings. Although the previous discussion outlined possible ways to operationalize the framework, further empirical studies are needed to examine how effectively the framework supports data collection, analysis, and interpretation in diverse ethnomathematical contexts.

Second, the analytical distinction among culture, practice, cognition, and mathematization may not always be clear in empirical settings. These dimensions are often deeply intertwined, and particular observations may simultaneously reflect multiple components. Consequently, researchers may differ in how specific phenomena are categorized, creating interpretive challenges and requiring careful justification of analytical decisions. This limitation reflects the complexity of ethnomathematical knowledge itself and highlights the importance of methodological transparency when applying the framework.

Third, the applicability of the framework across diverse cultural traditions remains a theoretical proposition. Although the framework was developed through a synthesis of ethnomathematics, sociocultural theory, distributed cognition, and mathematization studies, comparative research conducted in different cultural settings is needed to evaluate its transferability, explanatory scope, and potential limitations.

Finally, the framework is not intended to function as a universal methodological protocol. Rather, it serves as an analytical lens that may be adapted to different research questions, traditions, and forms of evidence. Future studies should therefore explore alternative operationalizations and empirical applications in order to evaluate its explanatory power, practical usefulness, and methodological flexibility.

Future research may extend the proposed framework in three directions. First, empirical studies are needed to examine how the framework operates across different ethnomathematical settings and to evaluate its explanatory usefulness in practice. Second, comparative research involving diverse cultural traditions may help identify both common patterns and context-specific variations in the relations among culture, practice, cognition, and mathematization. Third, further methodological development is needed to refine the operationalization of the framework through analytical protocols, coding schemes, and research designs suitable for qualitative, quantitative, and mixed-methods inquiry.

CONCLUSION

This article has proposed the CPCM framework as an integrative approach for interpreting ethnomathematical knowledge. Rather than treating ethnomathematics as a collection of isolated cultural examples, the framework provides a common analytical structure through which relations among culture, practice, cognition, and mathematization may be examined within a single perspective. A central contribution of the framework is its shift from descriptive identification toward process-oriented interpretation. Instead of asking only what mathematics can be found within a cultural practice, the framework directs attention to how ethnomathematical knowledge is constituted, sustained, transformed, and communicated across different contexts. In this way, it offers a basis for connecting and comparing diverse ethnomathematical cases while preserving their cultural specificity. The Mongolian *Ger* vignette illustrates one possible application of this perspective, demonstrating how cultural meanings, practical activities, cognitive processes, and forms of mathematization may be interpreted as interconnected dimensions of knowledge. More broadly, the framework can guide future empirical and comparative studies that examine ethnomathematical knowledge across different cultural traditions.

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