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Ethnomathematical insights from the tide-forecasting calendar of an Indonesian coastal community into mathematics classroom

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Abstract

The integration of culturally embedded knowledge systems into mathematics education has gained scholarly interest in recent years; however, empirical research remains limited, particularly in the context of Indonesian coastal communities where traditional ecological knowledge is closely tied to astronomical and environmental cycles. Despite the growing prominence of ethnomathematics, there is a noticeable paucity of studies that systematically investigate the mathematical reasoning inherent in indigenous calendrical systems used for livelihood practices. Addressing this gap, the present study explores the ethnomathematical knowledge embedded in the calendrical practices of the *Lungkak* community in East Lombok, Indonesia. This system uniquely integrates local interpretations of the *Pupuru* (the Pleiades star cluster), lunar phases, the Hijri calendar, and the Gregorian calendar to predict seasonal transitions and tidal patterns crucial to artisanal fishing. Employing an ethnographic research design, data were gathered through purposive sampling, in-depth interviews, participant observation, and document analysis, and analyzed using interactive ethnographic techniques. The findings uncover sophisticated mathematical reasoning within the community's calendrical system, including trigonometric concepts (angular relationships among celestial bodies), arithmetic and numerical sequences (predictive visibility patterns), modular arithmetic (cyclical astronomical forecasting), and set theory (classification of tidal phenomena). These insights reveal how formal mathematical concepts are embedded within cultural practices, demonstrating the community's implicit engagement with abstract reasoning. This study contributes to the development of culturally responsive mathematics education by emphasizing the pedagogical value of integrating ethnomathematical content into classroom instruction. Such integration holds potential to enrich students' mathematical literacy, foster contextual understanding, and support meaningful engagement with mathematical concepts through culturally relevant learning experiences.

Keywords: Coastal Community, Cultural Calendar, Mathematical Activities, Mathematical Concepts, Pleiades Star Cluster

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The origins of mathematics lie in the human drive to interpret, systematize, and navigate the natural world. Early manifestations of mathematical thinking emerged through the observation of patterns, the anticipation of natural phenomena, and the structuring of routine activities. As Utami et al. (2019) note, the evolution of mathematical knowledge is not a culturally neutral process but is shaped by the socio-environmental contexts in which it develops. Ethnomathematics—a field that examines the interrelationship between mathematical thought and cultural practices—has emerged as a critical interdisciplinary domain, bridging mathematical inquiry with cultural anthropology (Bleiler, 2015; D'Ambrosio, 2020). D'Ambrosio (2020) defines ethnomathematics as the mathematical ideas and practices of distinct cultural groups across various historical and developmental stages, revealing the diverse epistemologies that underpin mathematical activity.

As communities interact with their environment, they devise techniques, algorithms, and problem-solving strategies that serve both practical and abstract purposes. This adaptive engagement results in the emergence of mathematical reasoning grounded in experiential knowledge (Fauzi & Gazali, 2022). Rosa and Gavarrete (2017) describe ethnomathematics as encompassing the culturally rooted reasoning, representations, and procedures developed to address daily challenges. In this regard, mathematics is not a fixed body of universal truths but a dynamic human construct arising from socially embedded activities—such as counting, measuring, constructing, designing, and patterning (Ernest, 2018). These activities are not only functional but also culturally meaningful, embedded in community practices that reflect distinct ways of knowing and engaging with the world.

Recent scholarship has further elaborated on the culturally situated nature of mathematical thinking. For example, Batiibwe (2024) and Lubis et al. (2021) highlight how individuals draw upon culturally specific spatial and relational reasoning when navigating their environments, suggesting that mathematical activity is inextricable from cultural context. Such practices demonstrate that mathematical ideas do not exist in abstraction alone but are often enacted through embodied, spatial, and temporal interactions with one's surroundings.

Indonesia's rich ethnocultural diversity offers fertile ground for ethnomathematical inquiry, as traditional knowledge systems across the archipelago often contain embedded mathematical structures. Prior studies have shown that indigenous communities regularly engage in mathematical reasoning without formal instruction or symbolic notation (Prahmana et al., 2021). A salient example is the use of traditional calendrical systems, which rely on observations of natural cycles, periodic phenomena, and algorithmic patterns for organizing time. In the Javanese context, for instance, Prahmana et al. (2021) identify the presence of modular arithmetic in cultural timekeeping practices, used to determine significant life events and seasonal transitions. These systems, while not framed in conventional mathematical language, exhibit systematic reasoning and conceptual sophistication, reinforcing the role of ethnomathematics in identifying and validating informal mathematical knowledge.

Additional research has illuminated specific mechanisms by which traditional communities operationalize mathematical ideas. Arisetyawan and Supriadi (2020) describe how the *Badui* people calculate the beginning of a new month by adding two days to the first day of the previous month—an algorithmic rule consistent with arithmetic sequencing. Similarly, Utami et al. (2020) illustrate the potential for integrating such calendrical knowledge into elementary mathematics curricula, particularly for teaching concepts such as remainders and cyclical operations. As Deda (2024) argues, ethnomathematics not only enriches mathematics learning through cultural relevance but also contributes to broader goals of literacy, numeracy, and interdisciplinary education. Collectively, these studies affirm the pedagogical value of ethnomathematics as a means of contextualizing mathematical concepts and promoting inclusive, culturally responsive instruction.

Within this broader landscape, the ethnomathematics of the Sasak people on Lombok Island has received increasing academic attention. Scholars have explored the integration of mathematical ideas within

Sasak cultural practices (Kusaeri et al., 2019; Noor et al., 2024; Subarinah et al., 2022; Sutarto et al., 2021). For instance, Kusaeri et al. (2019) identify the potential of East Lombok's cultural heritage as a context for teaching abstract mathematical ideas through real-world, culturally authentic scenarios. Fauzi et al. (2022) further documents traditional Sasak measurement systems, highlighting the existence of systematic, non-formal mathematical knowledge in everyday life. These studies underscore the value of local knowledge in advancing mathematics education that is both contextually meaningful and pedagogically effective.

Moreover, Sasak material culture reflects a wide range of mathematical concepts. Studies of *Songket* Lombok, a traditional woven textile, demonstrate the application of transformational geometry through its symmetrical patterns and motifs (Hastuti, 2022; Muzaki et al., 2022; Sutarto et al., 2021). Ethnomathematical investigations have also extended to Sasak culinary practices and vernacular architecture, where elements of measurement, proportion, spatial reasoning, and symmetry are evident (Fauzi et al., 2022; Supiyati et al., 2019). These domains provide tangible resources for teaching mathematical concepts, reinforcing the potential of culturally embedded artifacts as instructional tools.

However, as Kusaeri et al. (2019) observe, much of the current ethnomathematical research in the Sasak context has focused primarily on material culture—such as textiles, buildings, and tools—while overlooking the broader systems of thought and reasoning that guide everyday practices. This narrow focus risks neglecting the underlying indigenous cultural logic (Enfield, 2000; Valentino, 2021) and indigenous knowledge systems (Hoppers, 2002; Khupe, 2020) that inform these practices and sustain their relevance. To address this gap, the present study investigates the implicit mathematical reasoning embedded in the calendrical system of the coastal community in *Lungkak* village, East Lombok. Specifically, it examines how community members use their indigenous knowledge system to predict ocean tides and plan fishing activities, thereby transforming calendrical tools into instruments of environmental decision-making.

In this community, calendrical reasoning is not confined to the tracking of dates but serves a critical function in managing ecological uncertainty and optimizing maritime practices. The *Lungkak* system integrates multiple time-reckoning frameworks, combining the appearance and positioning of the *Pupuru* (Pleiades star cluster) with elements of the Gregorian and Hijri calendars. This fusion supports the anticipation of seasonal and tidal shifts, functioning as a predictive tool grounded in environmental observation. Unlike prior studies that emphasize numerical patterns in cultural artifacts, this research foregrounds the abstract, yet systematic reasoning used in real-time navigation and subsistence planning.

Fishers in *Lungkak* village, for instance, rely on modular arithmetic to align fishing voyages with safe tidal conditions, demonstrating a form of applied mathematical reasoning that emerges organically from lived experience. These practices exemplify an underexamined dimension of ethnomathematics: the convergence of environmental knowledge, astronomical observation, and indigenous reasoning in community-based forecasting systems. By shifting the focus from static artifacts to dynamic cognitive processes, this study contributes to a more comprehensive understanding of ethnomathematical knowledge and its potential to inform culturally relevant mathematics education.

METHODS

This study employed a qualitative research design grounded in an ethnographic approach, which is particularly suited for investigating mathematical reasoning as situated within the cultural practices of a specific community. Ethnographic inquiry, rooted in interpretivist paradigms, seeks to produce a holistic understanding of cultural dynamics and social behaviors as they emerge within natural settings (Creswell

& Creswell, 2017). The research focused on the calendrical system of the *Lungkak* coastal community in Ketapang Raya Village, East Lombok, Indonesia—an indigenous timekeeping tradition that informs the community's maritime activities, particularly fishing. This system constitutes a cumulative body of cultural knowledge transmitted intergenerationally and embedded in daily decision-making processes. The ethnographic approach was adopted to examine how the calendrical system operates both as a socio-cultural structure and as a functional tool, offering insights into the relationship between community practices and localized mathematical reasoning.

The study aimed to explore not only the utilitarian aspects of the calendar—such as its role in predicting tides and structuring fishing schedules—but also its symbolic and epistemological significance within the community. In this way, the research investigated how mathematical thinking is embedded in and sustained by the social organization and cultural identity of the *Lungkak* villagers. The use of qualitative methods facilitated a nuanced understanding of the calendar as both a system of environmental knowledge and a site of informal mathematical engagement.

Data Collection

Data were collected through multiple ethnographic techniques, including document analysis, semi-structured interviews, and participant observation. The participants were selected via purposive sampling, targeting individuals with substantial knowledge and direct experience in using the calendrical system for practical purposes. The inclusion criteria required that participants, such as possess in-depth and experience-based understanding of the local calendar system, actively participate in the application of the calendar for fishing and related cultural practices, and be willing and available to engage in extended, detailed interviews (Hammond & Wellington, 2012). Three key informants were identified: a Sandro (traditional elder and knowledge keeper), a senior fisherman, and a *Penggawe* (leader of the fishing community), hereafter anonymized as S1, S2, and S3 respectively.

Data Analysis

Data were analyzed using Spradley's (1979) Developmental Research Sequence, which structures ethnographic analysis through four interconnected stages: domain analysis, taxonomic analysis, componential analysis, and thematic analysis. This approach allowed for a systematic investigation of how mathematical concepts are embedded within cultural practices. The analysis proceeded as follows: Domain Analysis: Identified broad semantic domains in which mathematical ideas are situated, such as celestial navigation, tidal forecasting, and seasonal transitions.

1. Taxonomic Analysis: Explored the internal structures of each domain to reveal the hierarchy and relationships among elements, such as classifications of tidal phases or star-based temporal markers.
2. Componential Analysis: Employed contrasting questions to identify critical features differentiating components within domains, thereby uncovering mathematical structures such as trigonometric relationships, modular operations, and arithmetic sequences.
3. Thematic Analysis: Synthesized patterns across domains to construct higher-order cultural themes that encapsulate the role of mathematics in the community's calendrical system.

A visual summary of this analytical sequence is provided in Figure 1, outlining the progression from field observations to abstracted ethnomathematical insights.

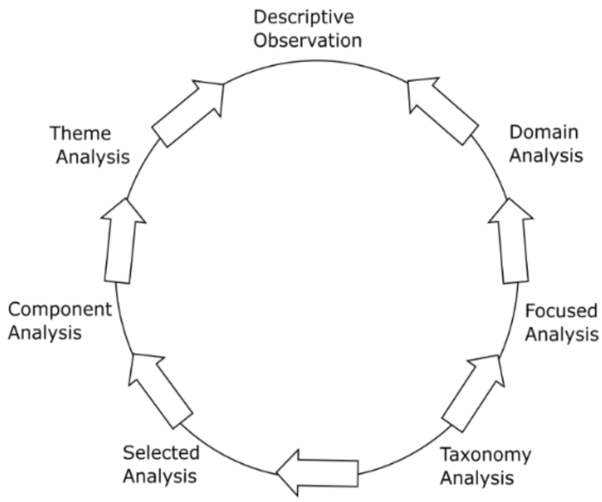

Figure 1. Spradley model data analysis process

Ethnographic Matrix

To enhance transparency and methodological coherence, Table 1 presents the ethnographic reasoning matrix adapted from Spradley (1979) and informed by Prahmana et al. (2021). This matrix maps four guiding ethnographic questions—where to start, how to look, what is it, and what does it mean—onto the specific research activities and mathematical constructs investigated in this study.

Table 1. Ethnographic research design for analysing mathematical concepts embedded in the coastal community's cultural calendar

General Ethnographic Question	Initial Answer Given the Study Focus	Starting Point (Cultural Locus)	Concrete Research Activities
Where to start looking?	In the coastal community's practices for forecasting tides and seasons.	Coastal cultural calendar (*Warige* board; *Pupuru* star cycle; and lunar phases).	• Select key culture-bearers (*Sandro*, senior fishers, and *Penggawe*). • Collect documents, artefacts, tide-record sheets, *Warige* boards. • Conduct semi-structured interviews on calendar construction and use.
How to look?	Examine how astronomical observations are converted into practical decisions for fishing.	Knowledge & technology system (astronomical observation, anthropometric gauges).	• Participant–observation of daily planning and boat departures. • Domain, taxonomic and componential analyses. • Record star– and moon-sighting routines; measure tide depth with indigenous units (*engke, pengekeang, peka',* and *pantar*).
What is it?	Evidence that these practices embed formal mathematical ideas.	Ethnomathematical perspective / philosophy of mathematics.	• Map *Pupuru* & lunar positions to angular values (0°, 90°, 180°). • Derive trigonometric, modulo-30 & modulo-3 models for tide cycles. • Identify arithmetic sequences and

			set classifications (*solong, ngerik, timbah,* and *konde*).
What does it mean?	The calendar is simultaneously a cultural heritage and a mathematical model that guides livelihoods.	Anthropological & educational relevance.	• Interpret how counting, measuring and calculating reinforce communal knowledge transmission. • Discuss potential for culturally responsive tasks in trigonometry, number patterns and modular arithmetic. • Propose curriculum links and future ethno-modelling work.

This matrix reflects the iterative and layered nature of ethnographic inquiry, progressing from embedded cultural practices to abstract mathematical formulations. For instance, the initial observation of fishers interpreting the *Pupuru* star's location (domain level) led to the identification of angular positioning and modular cycles as formal structures underlying empirical decisions. Componential analysis further revealed mathematical operations—such as arithmetic sequences and modular calculations—used to interpret and act upon environmental cues. These findings demonstrate that the calendrical system functions not merely as a cultural artifact but as a living mathematical model employed in the regulation of maritime activity.

By aligning research questions, data sources, and analytic procedures within a unified framework, the methodology ensures clarity and replicability. This design allows the study to serve not only as a contribution to the documentation of indigenous knowledge but also as a model for integrating ethnomathematics into mathematics education, particularly in ways that honor and elevate marginalized epistemologies.

RESULTS AND DISCUSSION

This section presents the empirical core of this study—how the coastal community calendar system operates, how tidal phases are recognized, and which mathematical structures (trigonometric angles, modular cycles, arithmetic sequences, set relations) underpin these practices. The subsequent discussion interprets these findings through an ethnomathematical lens, linking local knowledge to broader theory and to prospects for culturally grounded mathematics instruction.

Coastal Community Calendar System

The coastal community in *Lungkak* village, East Lombok, employs a unique calendar system integrating traditional astronomical observations with the Hijri and Gregorian calendars. Interviews with local community members revealed that the rising of the *Pupuru* star cluster (Pleiades) on the eastern horizon before dawn marks the beginning of the dry season or signals an impending seasonal transition.

Interviewer : *"Can you explain how people here construct their calendar?"*
Respondent S1 : *" The calendar culture of coastal communities is a cultural activity carried out as a basis for us to know natural phenomena related to events on land and at sea. In its implementation, we as coastal community calculate several astronomical objects such as stars and the moon. We need to calculate the calendar because we will know when we will be at sea."*

Respondent S2 : *" The people here calculate the calendar by calculating celestial objects such as stars and the moon. If we count the stars to calculate the month, we will look at the month to calculate the date. Because each date or month, these objects will have their respective positions."*

Respondent S3 : *" The calendar of the people here is calculated starting from the appearance of the Rowot/ Pupuru star in the Bajo language; usually, the star will appear in May. When its position in the sky is directly overhead, the fishermen determine it as Month 1."*

The coastal community divides the year into two main seasons: *Kembalit* (dry season), spanning months 1 through 6, and *Kentaung* (rainy season), covering months 7 through 12. Based on the knowledge and beliefs of the coastal community, these seasonal divisions directly influence tidal patterns. Community observations indicate that during the dry season, high tides occur primarily in the morning and low tides in the afternoon, whereas during the rainy season, high tides and low tides typically occur at night.

Table 2. Observational data on sea-level tides based on BMKG information (Central Indonesian Time—WITA, 25–30 January 2025 / 25–30 *Shaʿban* 1446 H)

Gregorian / Hijri Date	High-Tide Time (UTC)	Height (m)	Low-Tide Time (UTC)	Height (m)
25 Jan / 25 *Shaʿban*	20:00	1.36	03:30	0.51
26 Jan / 26 *Shaʿban*	21:00	1.47	03:40	0.49
27 Jan / 27 *Shaʿban*	21:30	1.57	04:00	0.50
28 Jan / 28 *Shaʿban*	22:10	1.66	04:20	0.50
29 Jan / 29 *Shaʿban*	22:50	1.72	04:50	0.51
30 Jan / 30 *Shaʿban*	23:40	1.73	05:40	0.38

The data in Table 2 show that high tide consistently peaks at night, while low tide occurs in the early hours of the morning—matching the coastal community's traditional understanding of seasonal patterns and tidal circulation. These detailed calculations and seasonal observations are systematically recorded on the *Warige* board (Figure 2), a wooden plank measuring roughly 45 × 15 cm. It bears symbolic inscriptions that guide fishers on auspicious and inauspicious times to sail, lunar positions, and the recurring seasonal patterns linked to the *Pupuru* star cluster. *Warige* boards are usually kept in the homes of customary leaders, because interpreting the symbols is reserved for individuals who hold the requisite authority and traditional knowledge—such as the *adat* elders or village chiefs.

The appearance of the *Pupuru* or Pleiades star cluster is an annual event marking the moment when the cluster first becomes visible again in the eastern sky just before sunrise. Astronomically, this is known as its heliacal rising. Because the synodic month—the 29.5-day lunar-phase cycle that underpins the Hijri calendar—does not match the sidereal year, the date of *Pupuru*'s rising in the lunar calendar drifts each year. As a result, the heliacal rising of *Pupuru* moves forward by about ten days in the Hijri calendar annually. This shift follows a stable 5-15-25 pattern: if *Pupuru* appears on the 5th day of a given Hijri month, it will appear on the 15th day the next year, then on the 25th day in the third year. After completing this three-year sequence, the cycle repeats, with *Pupuru* returning to the 5th day in the following year.

Additionally, the coastal villagers of *Lungkak* community closely observes the lunar cycle to determine daily dates. Notably, on the 1st and 15th of each Hijri month, the moon rises and sets simultaneously with the sun. Between these dates, the moon occupies three significant positions: *Seda'* (on the western horizon, day 1), *Tanggah* (perpendicular or zenith position, day 8), and *Pelua'* (on the eastern horizon, day 15). These lunar positions, meticulously recorded on the *Warige* board, enable precise alignment of daily activities with astronomical events, guiding the community's fishing schedules and cultural practices.

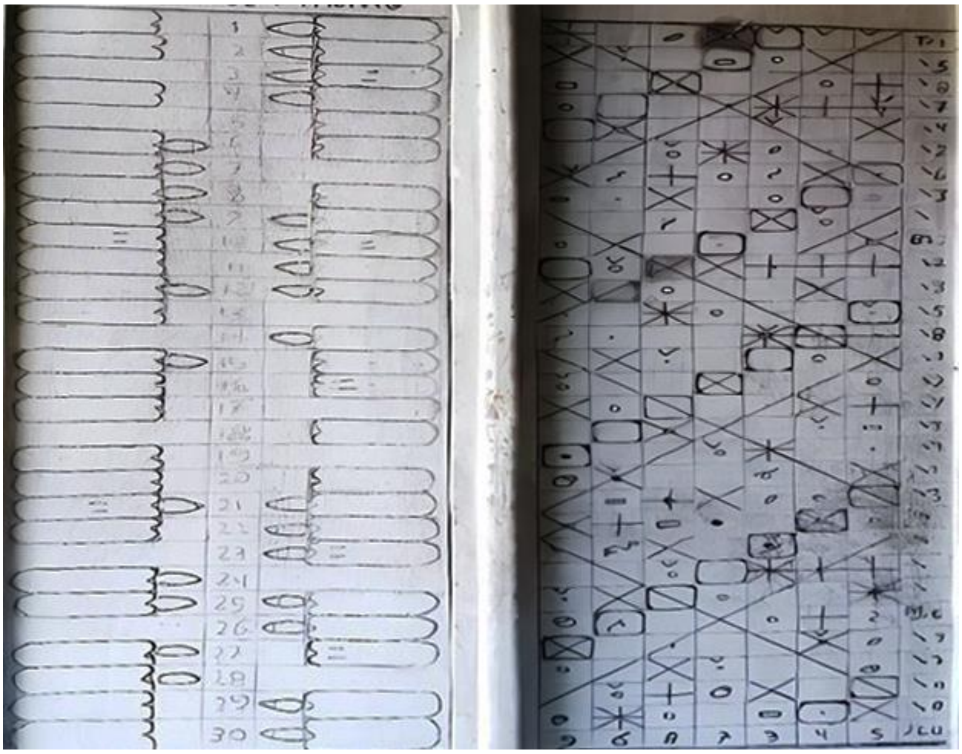

Figure 2. *Warige:* Traditional calendars system board

Beyond the records kept on the *Warige* board, this knowledge is typically passed on directly while at sea, because fishing is generally done at night. Under an open, light-pollution-free sky, fishers have optimal visibility to track the movement of stars and recognize the sky patterns that are central to their traditional navigation system. These moments double as intergenerational teaching occasions, linking cosmological wisdom to everyday practice.

Sea Tides in Coastal Communities' Calendar Culture

The coastal villagers of *Lungkak* community classifies the tides into four distinct phases: *Solong* (the rising-tide phase when the sea level is climbing), *Ngerik* (the ebbing phase when the sea level starts to fall), Konde (a period when the sea remains relatively stable with little movement), and *Timbah* (a transitional condition that lies between the *Solong*, *Ngerik*, and *Konde* phases). Their understanding of these tidal cycles is grounded in observations of the lunar phases. Interviews with community elders provided insights into how these tidal phases are predicted based on lunar observations.

Interviewer : *"How do people here know when the tides and ebbs occur? Is there a special calculation?"*

Respondent S1 : *"If people here calculate the tides by looking at the position of the moon, the tide will occur when the moon rises and sets. "*

Respondent S2 : *"If people here calculate the tides by looking at the moon's position. The tide will occur when the moon rises. The ebb and flow depend on the moon's appearance and position".*

Respondent S3 : *"People here calculate the tides by looking at the position of the moon; the tide will occur when the moon rises, and so does when the moon sets, while the ebb will happen when the moon has started to slide towards the west if the moon is in the middle, there is no high or low tide."*

The community estimates tidal heights by measuring seawater levels using traditional anthropometric units based on body parts, as summarized in Table 3. Although they are not as precise as conventional metric units, these traditional anthropometric measures are sufficiently accurate for local purposes. Equating lengths to parts of the body has long been common knowledge, handed down from generation to generation. It was the community's practical solution before standardized units or measuring devices existed. Measuring tidal height with these units still yields estimates that meet the fishermen's needs. These indigenous units—*Engke* (hand length), *Pengekeang* (adult arm span), *Peka'* (adult step length), and *Pantar* (¾ adult arm span)—are then converted into standard metric measurements.

Table 3. Traditional coastal community measurement units

No	Measurement Indicator	Value (cm)
1	*Engke*	20
2	*Pengkeang*	150
3	*Pekak*	50
4	*Pantar*	127

The coastal community associates each tidal phase—*solong, ngerik, konde*, and *timbah*—with specific dates in the lunar calendar. High tides (*solong*) typically occur during two key periods: the first four days of the lunar month and again from the 15th to the 18th day.

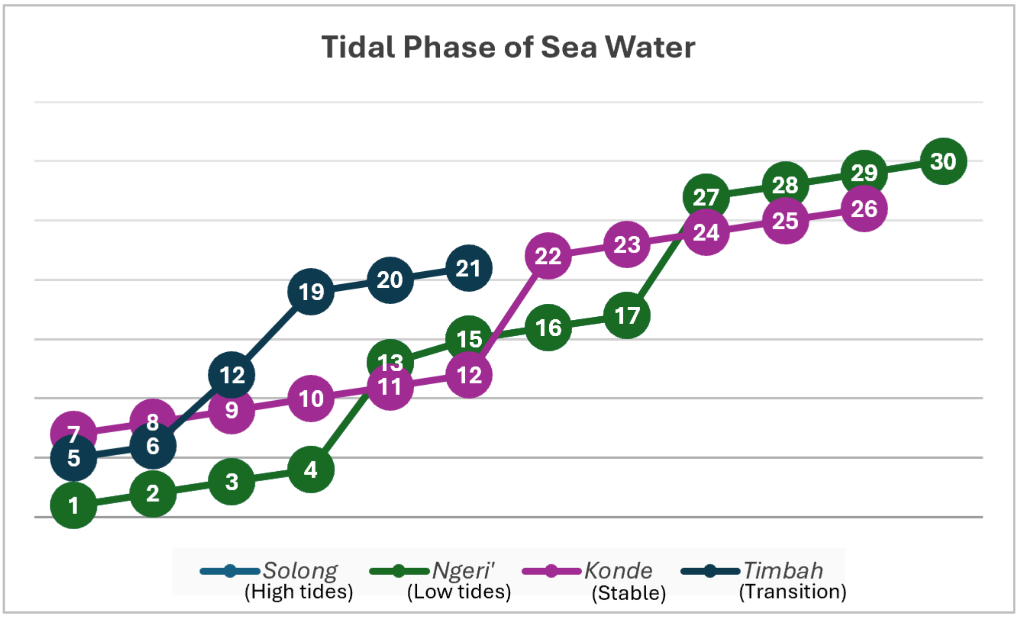

Figure 3. Tidal phase of sea water

The relatively stable tidal phase (*konde*) is observed between these intervals, specifically on days 7–11 and 22–26. Low tides (*ngerik*) consistently follow the high-tide phases, while transitional conditions (*timbah*) occur in the intervals linking the primary tidal phases. This structured temporal pattern, derived from careful lunar observations, enables the coastal community to plan and execute maritime activities in alignment with the natural rhythms of the sea. A visual representation of this cycle is provided in Figure 3.

Application of Mathematical Concepts in Calculating Sea Tides and Coastal Community Calendars

Trigonometric Calculations

The coastal villagers of *Lungkak* community employs specific terms—*seda', pelua'*, and *tanggah*—to describe the positions of the *Pupuru* star cluster and the moon. These positions correspond mathematically to specific angular measurements: *seda'* at 180°, *pelua'* at 0°, and *tanggah* at 90°. These angles are determined by tracking the moon's apparent movement from the eastern to the western horizon. Figure 4 illustrates the lunar cycle, highlighting these positions.

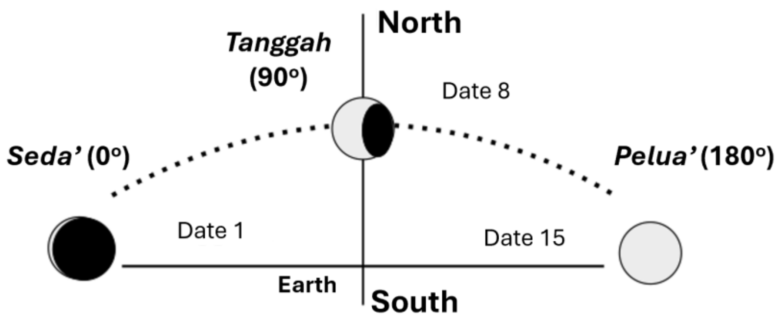

Figure 4. Lunar positions (*pelua', tanggah,* and *seda'*) relative to cardinal directions in the coastal calendar system

According to coastal communities, high tides (*solong*) occur when the moon is positioned at angles of 0° (*pelua'*) and 180° (*seda'*), while low tides (*ngerik*) correspond to moon positions between 90° and 180°, and between 270° and 360°. This cyclical tidal pattern is characteristic of semi-diurnal tides found around Lombok Island, producing two high tides and two low tides each day. Figure 5 and Table 4 clarify the angular divisions linked to tidal events.

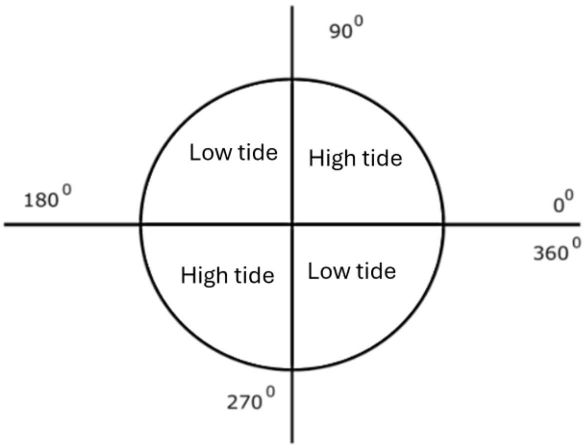

Figure 5. Angular positions of moon phases associated with sea water conditions

The data in Table 4 refers to the division of the angular area in each quadrant for the angular area 0^0 to 360^0. So, it can be said that the high tide will occur when the moon is in quadrants I and III, and then the low tide will occur when the moon is in quadrants II and IV.

Table 4. Classification of the angle for the occurrence of sea tides

No	Angle of month	Tidal Information
1	$0^0 < a < 90^0$	High tide (*solong*)
2	$90^0 < a < 180^0$	Low tide (*ngerik*)
3	$180^0 < a < 270^0$	High tide (*solong*)
4	$270^0 < a < 360^0$	Low tide (*ngerik*)

Number Patterns

Several numerical patterns underpin the coastal community's indigenous calendrical system. The appearance of the *Pupuru* star cluster follows a repeating three-year cycle characterized by the numerical sequence 5–15–25, with an annual shift of approximately 10 days. This celestial event consistently occurs in May. However, due to the discrepancy between the lunar and solar calendars, there is an annual drift of approximately 10.8675 days.

Leap-year adjustments within the system follow a fixed numerical series—2, 3, 5, 7, 10, 13, 15, 18, 21, 24, 26, 29—demonstrating an intuitive form of indigenous numerical abstraction and a rhythmic conceptualization of time. Despite lacking formal astronomical instruments or computational methods, the community's dating practices align closely with those of institutionalized lunar calendars such as the Hijri calendar.

Within a single lunar month, the tidal phases—*solong*, *ngerik*, *timbah*, and *konde*—follow a recurring numerical pattern (4–3–3–4–4–3–3–5 days). Furthermore, to determine the moon's age, the community applies a local number pattern referred to as *gena'-kurah-gena'-kurah*, which alternates between even (2n) and odd (2n–1) numbers, effectively modeling the synodic cycle of the moon (29 or 30 days). These practices exemplify how localized numerical reasoning supports culturally embedded timekeeping systems without reliance on formal mathematical apparatus.

Modulo Systems

The coastal community integrates a modulo number system into its calculations for both the Hijri calendar and the appearance of the *Pupuru* star cluster. The Hijri calendar repeats every 30 years. Community members determine a year's position within this cycle using modulo arithmetic. For example, the Hijri year 1443, calculated as 1443 mod 30, yields a remainder of 3, indicating that it is the third year in a 30-year cycle.

The *Pupuru* star cluster's appearance also follows a modulo-based cycle (modulo 3). For example, in Hijri year 1443, the calculation (1443 mod 3) yields a remainder of 0, indicating the star's appearance on the 25th day of the Hijri month. Thus, predictions for subsequent years follow this cyclic pattern (5th day, then 15th, then 25th, and back to the 5th).

Arithmetic Sequence

In the coastal community calendar system, observations from sunset reveal that between the 1st and the 15th day of the Hijri month, the moon completes a displacement of 180° clockwise. Consequently, over a full 30-day lunar cycle, a total displacement angle of 360° occurs in a clockwise direction. So, the difference in the displacement of the moon every sunset is $\frac{360^0}{30} = 12^0$ clockwise. Thus, the calculation of the angle of the moon on the n*th* date can be written mathematically as,

$$\alpha_n = 180^0 + (n - 1)b$$

where:

$$\begin{aligned} \alpha_n &= \text{Moon's angle in } n\textit{th} \text{ date} \\ n &= n\textit{th} \text{ Date} \\ b &= \text{difference in moon's angles} \\ \alpha_n &= (+)\text{the moon is above the horizon} \\ \alpha_n &= (-)\text{the moon is below the horizon} \end{aligned}$$

Furthermore, the lunar cycle duration of approximately 24 hours per day causes a 48-minute daily delay in moonrise and moonset times, calculated as follows: Moon's monthly revolution: 30 days × 24 hours = 1440 minutes and the daily delay is 1440÷30=48 minutes. Thus, the daily moonrise time (U_n) can be calculated by:

$$U_n = a + \frac{(n - 1)b}{60}$$

where:

U_n: Moonrise time on the nth day
a: Initial reference time (e.g., day 1 moonrise at 06:00)
b: Daily incremental delay in minutes (48 minutes)
n: Date number

The calculation of the moon setting can be obtained through the same calculation by replacing the initial reference point with the time the moon reaches an angle of 180^0 on the 1st, namely $a = 12{:}00$ with the same time difference, namely $b = 48$ minutes. However, it must be understood that these formulas are not recorded in any formal or written system; they are handed-down insights grounded in the coastal community's empirical observations. Therefore, although they can be expressed in mathematical terms for modern analysis and interpretation, the foundations of the system remain contextual and rooted in collective experience.

Set Theory

Coastal communities apply set theory implicitly when categorizing tidal phases. Each tidal condition (*solong, ngeri', konde*, and *timbah*) corresponds to a specific set of lunar dates:

A (High tide—*solong*): {1, 2, 3, 4, 15, 16, 17, 18}
B (Low tide—*ngeri'*): {1, 2, 3, 4, 15, 16, 17, 18}
C (Stable seawater—*konde*): {7, 8, 9, 10, 11, 22, 23, 24, 25, 26}
D (Transitional condition—*timbah*): {5, 6, 12, 13, 14, 19, 20, 21, 27, 28, 29, 30}

The four disjoint subsets of the Hijri month encode the cyclical behaviour of the sea. Sets A and B are structurally identical, reflecting the semidiurnal tidal pattern in which successive spring and neap tide peaks consistently occur on the same set of lunar dates. Their cardinalities ($|A| = |B| = 8$) correspond to the eight lunar days during which tidal fluctuations are most pronounced. Closure under union (e.g., $A \cup B \cup C \cup D = \{1,\ldots,30\}$) ensures a comprehensive classification of all lunar days, eliminating ambiguity in voyage planning.

The mutual disjointness between Set C and both Sets A and B (i.e., $A \cap C = B \cap C = \emptyset$) ensures that "stable-sea" periods never coincide with extreme tidal events—a feature strategically utilized by fishers when organizing net maintenance or conducting shoreline rituals. Complement operations further support risk management strategies: the complement of Set D corresponds exactly to $A \cup B \cup C$, indicating that all non-transitional days are predictably high, low, or stable. These categories are systematically encoded on the *Warige* board, providing immediate reference for night-time decision-making. By delineating tidal patterns through disjoint and collectively exhaustive numerical sets, the coastal community embeds formal mathematical reasoning—such as set theory and logical complementarity—into routine, culturally grounded maritime practices.

Discussion

The investigation into the integration of mathematical concepts within the coastal community's traditional calendar system for predicting sea tides revealed the utilization of several mathematical models and principles. Notably, the application of modulo arithmetic emerged as a critical tool in interpreting the cyclical appearance of the *Pupuru* star cluster (Pleiades) and aligning these observations with the phases of the Hijri calendar. This aligns with the findings of Utami and Sayuti (2020), who examined the traditional Javanese calendar and highlighted the use of modulo systems in determining *pasaran* market cycles. The similarity in the use of modular structures across different indigenous calendars indicates a recurring cognitive approach to cyclical phenomena, grounded in culturally situated mathematical reasoning. Furthermore, the study by Umbara (2021) describes the use of modular arithmetic in calculating the Sundanese calendar. The shared reliance on modular structures across various indigenous calendars points to a recurring cognitive approach to cyclical phenomena—one rooted in mathematical reasoning adapted to cultural contexts (see Table 5).

Table 5. Comparison of modulo systems in traditional calendars

Culture Model	Calculated Aspects	Modulo Used
Javanese Calendar	*Pasaran* (a five-day cycle in the Javanese calendar) days in Javanese tradition (*Legi, Pahing, Pon, Wage, Kliwon*)	Modulo 5
Sundanese calendar	*Indung Poe, Dewa Taun* (year), *Naktu Taun* (year), *Naktu* month, *Naktu* date	Modulo 7, 5, 8, 12
Calendar of the coastal community	30-year cycle of the Hijri calendar & the emergence of the *Pupuru* star	Cluster 30-year cycle of the Hijri calendar & the emergence of the *Pupuru* star cluster

Beyond modular arithmetic, this study also uncovers the implicit use of trigonometric reasoning in locating the *Pupuru* star cluster relative to the Moon; number-pattern analysis for tracking the cluster's annual progression; arithmetic sequences for situating the cluster within the semi-monthly cycle calculated by the Hijri calendar; and elements of set theory when classifying lunar positions (*solong*). These findings suggest that the coastal community's calendar system is not merely a cultural artifact but also a reflection of sophisticated mathematical thinking embedded in environmental and astronomical observations. This is because the traditional calendar that coastal communities use to predict the ebb and flow of the sea is, in fact, a mathematical practice that aligns with contemporary mathematical concepts. Karjanto (2024) emphasizes that mathematical understanding in traditional societies is often manifested through practices intertwined with everyday activities, supporting the notion that indigenous knowledge systems represent valid and rich sources of ethnomathematical inquiry. Our findings extend this perspective by demonstrating how mathematical abstractions are operationalized in the context of temporal prediction, particularly in maritime environments where environmental awareness is critical for community livelihood.

Furthermore, the mathematical concepts embedded in the coastal community's traditional calendar system can be systematically categorized into several core domains, with the concept of counting representing a foundational element. Counting, as a basic mathematical operation, serves as a critical tool for quantifying time intervals, measuring periodicity, and structuring temporal events. Within the local tradition, this practice is referred to as *ngarekeh* (calculate the date), a culturally embedded term that denotes the act of quantifying values or magnitudes. In the context the villagers of *Lungkak* calendar system, counting is utilized to sequence the progression of time, particularly through the orderly arrangement of months and days. The coastal villagers of *Lungkak* still perform calculations with their traditional calendar before heading out to sea. These computations are carried out by the fishers themselves, assisted by customary elders who are regarded as having greater expertise in interpreting the *Warige* calendar.

This system employs unique terminologies that reflect both temporal and astronomical understanding. For instance, the term law is used to represent a single day, equivalent to a 24-hour cycle; *taek* refers to a full month; and *taung* denotes an entire year. These temporal units are essential for structuring routines and activities that are highly dependent on environmental rhythms, such as fishing and coastal navigation. Furthermore, the system incorporates specialized terms to describe the moon's phases and apparent shapes, reflecting an observational awareness of lunar cycles. The term *peres* indicates one-third of the moon's visibility, while *buntar* signifies the full moon, characterized by a complete circular appearance. These linguistic and conceptual representations indicate the presence of informal mathematical abstraction, demonstrating how culturally specific knowledge systems utilize measurement, enumeration, and geometric reasoning in harmony with ecological and astronomical phenomena.

The second key mathematical concept embedded within the coastal community's calendar system pertains to directional orientation, a domain that integrates spatial reasoning with environmental and astronomical observation. The community recognizes five cardinal directions, namely *manungare* (southeast), *wara*' (north), *bara*' (west), *dilauk* (east), and *timbor* (south). These culturally specific directional terms reflect a nuanced understanding of spatial orientation adapted to the coastal geography and seafaring livelihood. Traditional navigation practices are deeply reliant on celestial navigation; wherein various astronomical bodies serve as reliable reference points during maritime travel.

To ascertain the east-west axis, the moon is commonly employed as a primary marker. However, in instances when the moon is obscured or below the horizon, navigators shift their reliance to stellar constellations, particularly the *Pupuru* star cluster and *Tatalu* (the name of the star that appears to form a formation like a rice field plow), both of which follow an east-west apparent motion. For identifying the southeast direction, the Pai star functions as a consistent reference point. This practice reveals a sophisticated integration of astronomical observation and geometric directionality, demonstrating the community's empirical understanding of diurnal and seasonal star movements. In addition to celestial markers, natural oceanic phenomena—such as tidal flow and wave direction—are also utilized. During high tide, ocean currents move landward, while in low tide conditions, they recede toward the open sea. Moreover, wave trajectories, which invariably approach the coastline, serve as consistent indicators of landward orientation. These patterns provide a secondary system of spatial reference, reinforcing the mathematical grounding of traditional navigation.

The third mathematical concept identified involves non-standard measurement systems, particularly concerning magnitude, dimension, and capacity. In the context of sea tide observation, the coastal community employs an anthropometric measurement system, wherein parts of the human body are utilized as referential units. This practice, deeply rooted in indigenous knowledge systems, provides a practical and accessible means of quantification. Among the measurement units documented are *engke* (a generalized unit of length), *pengekeang* (the span of an adult's arms), *peka'* (the stride length of an adult), and *pantar* (approximately three-fourths of an adult's arm span). These anthropometric units are traditionally applied to determine sea depth, particularly during various tidal phases, with each phase corresponding to a specific depth classification. The use of the human body as a referential instrument reflects a form of contextual and embodied mathematics, in which quantification arises from lived experiences and ecological engagement rather than abstract formalism.

Collectively, these findings substantiate the argument that indigenous calendrical and navigational systems are underpinned by structured mathematical thinking. The spatial, numerical, and measurement-related concepts evident in the coastal community's practices offer fertile ground for further exploration within the framework of ethnomathematics, aligning with contemporary efforts to recognize and integrate culturally responsive mathematical education (D'Ambrosio, 2020; Septianawati & Puspita, 2017).

The findings of this study affirm the reciprocal relationship between mathematics and culture, wherein cultural practices provide fertile ground for mathematical inquiry, and mathematical frameworks, in turn, offer tools for interpreting and formalizing cultural knowledge. As articulated by Brown (2019), mathematics and culture operate in a symbiotic manner, bridging theoretical constructs with practical application through lived experiences. This interplay becomes particularly salient in specific cultural contexts where mathematical reasoning is deeply embedded in everyday practices, rituals, and artistic expressions. Anderson (2021) underscores this by arguing that both traditional and modern (urban) communities engage in mathematically significant activities, and their artistic and cultural artifacts can serve as valuable sources for mathematical exploration and abstraction.

The ethnomathematics approach, as posited by Thomas (2024), offers a powerful pedagogical model through which mathematical concepts can be constructed from culturally situated knowledge. Rather than adhering to a static curriculum, the principles of ethnomathematics emphasize dynamic learning environments where learners engage with tasks rooted in familiar cultural contexts. This method facilitates contextualized learning, enabling students to draw connections between environmental experiences and formal mathematical content encountered in the classroom. By interacting with culturally relevant mathematical phenomena, students actively construct knowledge, leading to deeper conceptual understanding and enhanced cognitive engagement.

As an example of applying ethnomathematics in trigonometry lessons, one can use the heliacal appearance of the *Pupuru* star cluster. Suppose students are asked to calculate the altitude of *Pupuru* in the sky, given an elevation angle of 15° and a horizontal distance of 30 km from the observer. Using the trigonometric relationship, tan(θ)= opposite/adjacent, they compute height = $\tan(15^\circ) \times 30 \approx 0.2679 \times 30 = 8.04$ km. This result shows that *Pupuru* is situated roughly 8.04 km above the horizon.

Furthermore, the integration of cultural knowledge in mathematics instruction yields dual benefits: it enriches mathematical comprehension while simultaneously fostering cultural appreciation. As noted by Makur (2019), this duality supports the development of inclusive educational models that validate diverse ways of knowing. Cultural activities serve not only as vehicles for mathematical learning but also as mediums for honoring and preserving indigenous knowledge systems. Duffy (2021) supports this view, highlighting that such integration enhances the diversity and relevance of mathematical learning experiences, particularly in multicultural contexts. In alignment with this perspective, Bussi (2023) emphasizes that mathematics, as a scientific discipline, must preserve its core values while remaining open to the incorporation of local cultural elements in pedagogical practices. Therefore, embedding ethnomathematical perspectives within the curriculum not only aligns with principles of equity and inclusivity but also promotes a more meaningful and authentic mathematics education.

According to Vygotsky's sociocultural theory, "the meaning of mathematical concepts and the validity of mathematical statements are socially accomplished," highlighting the critical role of cultural and contextual experiences in mathematical cognition. This theoretical stance underscores the importance of introducing mathematical concepts through familiar, everyday language, which enhances accessibility and understanding among students. For instance, Kusaeri et al. (2019) emphasize that terms such as "taken away" or "lost" are more meaningful to learners when introducing subtraction, as these expressions mirror real-life situations. This contextualization facilitates a deeper grasp of mathematical operations by linking abstract concepts to tangible experiences.

Expanding on this perspective, Rosa and Orey (2013; 2022) propose the ethno-modelling approach, which advocates for the integration of local cultural elements into mathematics instruction through mathematical modeling. Ethno-modelling enables educators to bridge the gap between formal mathematical language and indigenous knowledge systems, creating more inclusive and relevant learning experiences. Desai et al. (2022) and Furuto (2014) similarly argue for the deliberate design of mathematics instruction that not only respects but also incorporates local cultural practices. Several other studies of traditional calendars underscore their value for culturally integrated mathematics curricula. For instance, the Chinese calendar—whose basic principles are partly shaped by Indian trigonometric concepts—has been deemed well suited to designing culture-rich mathematics (Yao-Yong & Wen-Lin, 2011). Likewise, a lesson on least common multiples centered on the Mayan calendar enabled students not only to appreciate an ancient civilization but also to draw on their classmates' cultural backgrounds during mathematics instruction (Taylor et al., 2015). By doing so, educators foster a learning environment where mathematical concepts are not perceived as isolated abstractions but are instead rooted in lived experiences.

Empirical studies further support this approach. Sudirman et al. (2024) demonstrate that the mathematical practices of local communities can be transformed into culturally relevant story problems, while Shultz et al. (2022) show how these practices can be embedded within STEM-based instructional tools. These strategies not only enhance students' engagement but also cultivate their ability to apply mathematical reasoning across diverse contexts, particularly when supported by digital technologies. In light of these findings, the mathematical elements embedded in the coastal community's calendar system—such as trigonometry, modulo arithmetic, arithmetic sequences, and set theory—offer rich opportunities for curriculum integration. These indigenous mathematical constructs, especially as they relate to predicting sea tides, exemplify how traditional knowledge can be aligned with school mathematics content. Therefore, future research will focus on the systematic integration of these contextual insights into formal mathematics curricula, ensuring both cultural relevance and mathematical rigor in instructional design.

CONCLUSION

This study demonstrates that mathematical reasoning is deeply embedded in the cultural practices of the coastal community in *Lungkak*, East Lombok. The community's calendrical system—used to forecast tidal patterns and seasonal transitions essential to artisanal fishing—reveals a sophisticated integration of observational astronomy with multiple calendrical frameworks, including the Hijri and Gregorian systems. Central to this tradition is the *Pupuru* (Pleiades star cluster), whose visibility and angular position, in conjunction with lunar phases, serve as key indicators for temporal regulation. Through ethnographic inquiry, the research uncovered several formal mathematical structures underlying these practices, including trigonometric reasoning (angular positioning of celestial bodies), arithmetic sequences (daily and monthly displacement of stars and lunar phases), modular arithmetic (cyclical alignment of star and calendar systems), numerical patterns (recurring celestial events), and implicit set theory (classification of tidal phases). These findings affirm that mathematics, far from being a culturally neutral discipline, is intricately interwoven with local knowledge systems and embodied in lived experiences.

While the study offers a rich ethnomathematical account of calendrical practices in *Lungkak*, it is not without limitations. First, the scope of the research was restricted to a single community and primarily focused on a small number of key informants selected through purposive sampling. As such, the findings may not fully capture the diversity of calendrical reasoning across other coastal or inland communities with similar or differing ecological and cultural conditions. Second, the study emphasizes qualitative exploration and theoretical interpretation rather than empirical testing or instructional implementation. Although mathematical structures were identified within the community's practices, these were not translated into formal pedagogical frameworks or systematically evaluated for educational impact. As a result, the study remains at the intersection of ethnographic documentation and theoretical modeling, without yet extending into the domain of applied educational research.

Future research should address these limitations by developing and testing culturally responsive mathematics instructional designs grounded in ethnomathematical findings. In particular, the mathematical constructs derived from the *Lungkak* calendrical system—such as modular arithmetic, trigonometric relationships, and pattern recognition—could be transformed into lesson plans, problem-based learning modules, or ethnomodelling activities tailored to students' cultural backgrounds. These educational interventions should be empirically evaluated to assess their effectiveness in enhancing students' mathematical understanding, engagement, and identity development. More broadly, this study contributes to the growing body of scholarship that seeks to decolonize mathematics education by recognizing and validating diverse epistemologies. Integrating indigenous knowledge systems into mathematics curricula not only affirms cultural identity but also cultivates a more inclusive and equitable vision of mathematics as both a universal and culturally situated discipline.

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