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Ethnomathematics in the *Tumbu Tanah* dance: Geometric, rhythmic, and symbolic patterns among the Arfak people of West Papua, Indonesia

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Abstract

Indigenous cultural practices in eastern Indonesia, particularly West Papua, remain underrepresented in ethnomathematics research. This study examined ethnomathematical ideas embedded in the *Tumbu Tanah* Dance of the Arfak people, focusing on geometric, rhythmic, and symbolic patterns manifested through embodied cultural practices. Guided by D'Ambrosio's ethnomathematics framework and Indigenous epistemological perspectives, this qualitative ethnographic study employed participant observation, semi-structured interviews with twelve cultural elders and master performers, and visual and kinematic documentation. Data were analyzed using thematic, geometric, and movement analyses to identify mathematical ideas in the dance's choreography, rhythm, and social organization. The findings identified three principal formations: *jey/srem* (linear), *ikrop* (semicircular), and *nimot* (circular), which demonstrate geometric ideas related to symmetry, rotation, curvature, and spatial proportion. Rhythmic foot-stamping patterns reflected periodicity, recursive sequencing, and temporal synchronization, while dancer arrangements based on kinship and ceremonial roles reflected grouping, partitioning, and numerical distribution. These mathematical ideas are transmitted through embodied movement, communal participation, and intergenerational cultural practices rather than formal mathematical notation. The study demonstrates that *Tumbu Tanah* constitutes a culturally situated context for recognizing mathematical ideas within Indigenous knowledge and offers potential for culturally responsive mathematics education and cultural heritage preservation.

Keywords: Culturally Responsive Mathematics Education; Embodied Mathematics; Ethnomathematics; Indigenous Knowledge; *Tumbu Tanah* Dance

Introduction

Traditional cultural practices in Indigenous communities are important sources of collective knowledge, social values, and cultural identity. Practices such as rituals, music, and dance serve not only aesthetic or entertainment purposes but also provide ways for communities to communicate values, maintain social relationships, and transmit knowledge across generations (Kawagley, 2006; Smith, 2021; Way et al., 2024). From the perspective of Indigenous epistemologies and culturally sustaining pedagogy, these practices can be understood as legitimate contexts for knowledge production and transmission rather than merely as cultural objects for documentation (Chilisa, 2020; Paris & Alim, 2017). In this context, traditional performances may provide opportunities to examine how communities develop and express knowledge through movement, space, rhythm, and social interaction.

In Papua, Indonesia, traditional arts are closely connected to communal life, customary practices, and relationships with the natural environment. Artistic expressions are used to communicate social and cultural meanings and to maintain connections among community members, ancestors, and the surrounding environment (Grenard, 2019). Dance is particularly important because bodily movement, spatial arrangement, rhythm, and collective participation are closely related to communal identity and social relationships. The Arfak people are one of the major Indigenous groups in the Arfak Mountains region of West Papua. The Arfak community consists of four closely related subgroups, namely *Hattam*, *Meyakh*, *Moile*, and *Sough*, which maintain distinct linguistic traditions while sharing several cultural practices (Koentjaraningrat, 1994). One of these practices is the *Tumbu Tanah* Dance, also known as *Dansa Tumbu Tanah* or *Tarian Ular* (Snake Dance). The dance is traditionally performed during various communal and customary events, including welcoming guests, harvest celebrations, weddings, and other traditional ceremonies. It represents gratitude, cultural continuity, and communal harmony.

The organized movements of *Tumbu Tanah* also provide an opportunity to examine mathematical ideas embedded in cultural practice. The dance involves coordinated formations, directions, distances, rhythmic patterns, and positional relationships among dancers. These features are relevant to ethnomathematics, which recognizes mathematics as knowledge and practice developed and used within particular cultural contexts (D'Ambrosio, 2006; Barton, 1996; Rosa & Orey, 2016). From this perspective, mathematical ideas do not exist only in formal symbols and procedures but may also be expressed through everyday cultural activities involving space, quantity, patterns, and relationships. The embodied nature of dance is particularly relevant because movement and spatial interaction can support the development and expression of spatial reasoning (Khatin-Zadeh et al., 2022; Lakoff & Núñez, 2000; Nemirovsky & Borba, 2014). Spatial reasoning is an important component of mathematical thinking and is related to learners' understanding of geometry, measurement, and transformations (Harris et al., 2023; Thom & McGarvey, 2022). Thus, the formations and movement patterns in *Tumbu Tanah* can be examined in relation to mathematical ideas such as linearity, circularity, symmetry, rotation, transformation, and spatial proportion.

Although ethnomathematics research has increasingly examined mathematical ideas in cultural practices, studies in Indonesia have more commonly focused on relatively static cultural objects, including weaving patterns, architectural forms, ornaments, and traditional tools (As'ari et al., 2020; Batiibwe, 2024; Risdiyanti & Prahmana, 2017). Dynamic and embodied cultural practices, particularly traditional dances, have received comparatively less attention. Existing studies of *Tumbu Tanah* have mainly emphasized its cultural meaning, ethnographic characteristics, and preservation. Systematic investigations of the mathematical structures associated with its choreographic formations and movement patterns remain limited. Consequently, the potential of *Tumbu Tanah* as a context for understanding Indigenous spatial reasoning and ethnomathematical ideas has not been sufficiently explored (Deda et al., 2024). This gap is also relevant to mathematics education because culturally situated mathematical practices can provide meaningful contexts for connecting formal mathematical concepts with students' cultural environments (Gutiérrez, 2013; Meaney, 2019). At the same time, research involving Indigenous knowledge requires attention to cultural ownership, community participation, and ethical knowledge production. Indigenous research methodologies emphasize reciprocity, cultural respect, and epistemic responsibility when documenting and interpreting Indigenous knowledge (Chilisa, 2020; Madimabe-Mofokeng et al., 2025; Smith, 2021).

Therefore, this study examined the ethnomathematical ideas embedded in the *Tumbu Tanah* Dance of the Arfak people in West Papua, Indonesia. Specifically, the study aimed to: (1) identify and analyze mathematical ideas reflected in the dance's choreographic formations and movement patterns; (2) interpret the cultural meanings and social values associated with these formations; and (3) examine the potential contribution of the findings to culturally responsive mathematics education and Indigenous cultural preservation. Accordingly, the study addressed the following research questions: (1) How do the choreographic formations and movement patterns of the *Tumbu Tanah* Dance reflect mathematical ideas and spatial relationships? (2) What cultural meanings and social values are associated with these mathematical formations? and (3) How can the ethnomathematical analysis of the *Tumbu Tanah* Dance contribute to culturally responsive mathematics education and Indigenous cultural preservation? By addressing these questions, the study contributes to ethnomathematics research by documenting mathematical ideas within an underexplored Indigenous cultural practice and by demonstrating how embodied cultural practices can provide culturally situated contexts for understanding mathematics.

Methods

This study employed a qualitative ethnographic design to investigate the ethnomathematical ideas embedded in the *Tumbu Tanah* Dance of the Arfak people in West Papua, Indonesia. The study was guided by three complementary perspectives: ethnomathematics, embodied cognition, and Indigenous research methodologies. Ethnomathematics views mathematical knowledge as culturally situated and developed through everyday practices (D'Ambrosio, 2006; Rosa & Orey, 2016). Embodied cognition emphasizes the role of bodily experience,

movement, spatial orientation, and interaction with the environment in the development of mathematical understanding (Lakoff & Núñez, 2000; Nemirovsky & Borba, 2014). Indigenous research methodologies emphasize relational accountability, cultural reciprocity, and respect for Indigenous knowledge and community perspectives (Chilisa, 2020; Smith, 2021).

These perspectives guided the researchers in examining the mathematical structures of the dance without separating them from their cultural meanings. Geometric and spatial concepts were therefore used as analytical tools to describe patterns observed in the choreography, while interpretations of these patterns were grounded in the cultural explanations provided by dancers, elders, and customary leaders. This approach enabled the study to address the three research questions by combining spatial-geometric analysis, cultural interpretation, and community-based validation.

Research Context and Participants

The fieldwork was conducted from March to April 2026 in Arfak highland communities in Manokwari Regency, West Papua Province, Indonesia. The *Tumbu Tanah* Dance continues to be performed in ceremonial, agricultural, and social contexts within these communities.

Participants were selected through purposive sampling in consultation with the Indigenous Council of Papua Region III and local customary leaders. The final participants comprised 12 cultural knowledge holders: six experienced *Tumbu Tanah* Dancers (three males and three females, aged 28–52 years), four cultural elders involved in ritual transmission and the preservation of the dance, and two customary coordinators responsible for community performances. Participants were selected based on their experience with *Tumbu Tanah*, active involvement in traditional performances, and recognized knowledge of the cultural practices associated with the dance. Written and verbal informed consent was obtained from all participants in accordance with institutional ethical requirements and relevant community protocols.

Data Collection Procedures

Data were collected through a multimodal ethnographic approach combining participant observation, semi-structured interviews, and audiovisual and spatial documentation. These methods were used to examine both the observable movement patterns of the dance and the cultural meanings attributed to them by community members.

The researchers observed eight live *Tumbu Tanah* performances and five rehearsal sessions in *Anggi*, *Hingk*, and surrounding Arfak communities. Observations focused on choreographic formations, spatial transitions, rhythmic synchronization, directional alignment, and interactions among dancers. Field notes included descriptive accounts, spatial sketches, and reflective notes concerning recurring movement patterns and their cultural contexts.

Semi-structured interviews were conducted with cultural practitioners and elders to explore the historical, ritual, social, and ecological meanings of *Tumbu Tanah*. The interview questions were developed in consultation with community advisors to ensure cultural appropriateness. The interviews addressed four main areas: (1) the historical and ritual

functions of *Tumbu Tanah*; (2) Indigenous interpretations of movement formations and spatial arrangements; (3) traditional rules governing choreography and participation; and (4) community perspectives on collective coordination and relational harmony. The interviews were conducted in Indonesian, with clarification in the Arfak language when necessary. All interviews were audio-recorded with participants' consent, transcribed verbatim, and translated with contextual checking by bilingual cultural liaisons.

Multi-angle video recordings were used to document individual movements, group formations, and spatial trajectories during performances and rehearsals. The recordings were reviewed frame by frame to examine changes in formations and movement patterns. Spatial documentation also included overhead photographs and time-stamped video records to support the analysis of formations, rhythmic sequences, and positional changes. The visual data were primarily used to identify recurring geometric configurations, symmetry, spatial relationships, and movement transformations while minimizing disruption to the performance context.

Data Analysis

The data were analyzed iteratively through four interconnected stages: cultural-thematic analysis, embodied-spatial mapping, ethnomathematical interpretation, and integrative triangulation.

1. Cultural-Thematic Analysis
   Interview transcripts and field notes were analyzed using both inductive and deductive coding. Initial coding identified recurring ideas related to social cohesion, ecological relationships, ancestral continuity, and communal identity. Related codes were then grouped into broader themes that supported the interpretation of the cultural meanings associated with particular dance formations and movement patterns. This stage primarily addressed the second research question concerning the cultural meanings and social values embedded in the dance.
2. Embodied-Spatial Mapping
   The video recordings were analyzed frame by frame to identify recurring choreographic formations and movement trajectories. Linear, circular, semicircular, and serpentine configurations were mapped using spatial grids and trajectory tracing. Particular attention was given to directional alignment, distances between dancers, symmetry axes, and rotational or transitional pathways. These observations provided the basis for identifying recurring spatial relationships within the dance.
3. Ethnomathematical Interpretation
   The identified spatial and movement patterns were interpreted using mathematical concepts relevant to geometry and transformation, including parallelism, symmetry, rotational transformation, translational movement, and coordinate positioning. These concepts were used as analytical tools to describe mathematical relationships observed in the dance rather than as replacements for Indigenous interpretations of the practice. Each identified mathematical pattern was compared with the cultural themes derived from

interviews and observations to maintain the connection between mathematical interpretation and cultural context.

4. Integrative Triangulation and Framework Development
   The mathematical patterns and cultural meanings were subsequently integrated to develop a culturally grounded analytical framework of *Tumbu Tanah*. The preliminary interpretations were discussed with cultural advisors and participants to obtain feedback, identify possible misunderstandings, and enrich the interpretation of the findings. The final framework connected three dimensions of the dance: embodied movement, spatial-geometric structures, and Arfak cultural and social values. This stage addressed the third research question concerning the potential contribution of ethnomathematical analysis to culturally responsive mathematics education and community-based cultural preservation.

Trustworthiness, Positionality, and Ethical Considerations

The trustworthiness of the study was supported through prolonged engagement with the research context, triangulation of multiple data sources, reflexive documentation, and participant validation. Observational notes, interview accounts, and audiovisual records were compared to identify consistencies and differences in the interpretation of movement patterns. The researchers also maintained a positionality journal to reflect on their assumptions, cultural perspectives, and relationships with participants throughout the research process.

Preliminary interpretations were discussed with cultural advisors and participants to reduce the risk of misinterpretation and to ensure that the mathematical analysis remained consistent with the cultural meanings of the dance. This process was particularly important because the study involved interpreting Indigenous cultural knowledge through an academic framework.

The study also followed principles of cultural respect, reciprocal engagement, and responsible use of Indigenous knowledge. Participants retained rights over their cultural narratives and performance recordings, and the researchers discussed the intended use of the collected materials with community representatives. Dissemination materials will be made available to the community in accessible formats, and the findings will be shared through local cultural activities where appropriate. The *Tumbu Tanah* Dance was therefore treated as a living cultural practice rather than merely as an object of mathematical analysis. This approach is consistent with Indigenous research methodologies that emphasize relational accountability, cultural integrity, and respect for Indigenous knowledge (Chilisa, 2020; Smith, 2021).

Results and Discussion

The Arfak people are one of the largest indigenous communities living in the central highlands of West Papua, Indonesia. They are particularly concentrated in the contemporary administrative areas of Manokwari Regency and South Manokwari Regency. The Arfak community is traditionally made up of four closely related ethnolinguistic groups: the *Hattam*, the *Meyakh*, the *Sough*, and the *Moile*. While each subgroup has its own linguistic

characteristics and local cultural expressions, they share a socio-cultural foundation based on customary law (*adat*), kinship systems, ancestral beliefs and collective cultural traditions. This shared cultural heritage fosters a strong sense of communal identity, transcending linguistic differences and reinforcing social cohesion across the Arfak Mountains region.

The cultural life of the Arfak community is inextricably linked to the mountainous environment in which it has evolved for generations. Located within the Bird's Head Peninsula of West Papua, the Arfak Mountains are more than just a geographical feature; they are a culturally significant landscape with historical, spiritual and ecological importance. For the Arfak people, the surrounding forests, rivers, mountains and valleys are not just physical resources, but integral components of their living environment, shaping their social organization, cultural values and collective memory. The relationships between humans, nature, and ancestral spirits are viewed as interconnected and mutually supportive, forming the basis of indigenous ecological knowledge and cultural practices.

In this worldview, cultural performances have functions that extend far beyond artistic expression. Traditional dances, songs, oral narratives and ceremonial gatherings are important mechanisms for transmitting knowledge across generations, preserving social norms, strengthening communal bonds and maintaining cultural continuity. These cultural practices also serve as repositories of historical memory, moral values and environmental wisdom, ensuring that cultural knowledge remains embedded in everyday communal life.

Among the various cultural expressions maintained by the Arfak community, the *Tumbu Tanah* Dance occupies a particularly significant position. Recognized as one of the Arfak people's most emblematic traditional performances, it is performed during various social and ceremonial occasions, including guest receptions, harvest celebrations, customary festivals, weddings, reconciliation ceremonies, community gatherings, and other collective events. Its continued performance across generations reflects its enduring importance as a medium through which cultural identity is expressed and reaffirmed.

Ethnographic interviews conducted during this study revealed that community members do not merely perceive the *Tumbu Tanah* Dance as a form of entertainment or artistic performance. Instead, they understand it as a symbolic embodiment of communal values emphasizing solidarity, cooperation, mutual respect and collective responsibility. Participants often described the dance as representing togetherness, in which individuals move as one while being mindful of their relationships with fellow community members, ancestors, and the natural environment. Through its collective choreography, rhythmic coordination and spatial organization, the dance visually and symbolically expresses the principles of social harmony and communal interdependence that underpin Arfak society.

Furthermore, the *Tumbu Tanah* Dance is a means of enacting and transmitting cultural knowledge. Its movements, formations, rhythmic patterns and ceremonial contexts embody layers of meaning that connect contemporary participants with ancestral traditions. Therefore, the dance functions simultaneously as a cultural performance, a social institution and a mechanism for transmitting knowledge across generations. Its persistence in contemporary

Arfak society demonstrates the resilience of indigenous cultural practices in maintaining a collective identity amid ongoing social and cultural change.

To interpret the mathematical structures identified in this study, it is essential to understand the cultural significance of the *Tumbu Tanah* Dance. The geometric formations, rhythmic cycles, spatial arrangements and transformational movement patterns observed during performances do not emerge from isolated mathematical abstractions imposed by external analysis. Instead, they emerge organically from culturally significant practices that have been developed, maintained and passed down through generations within the Arfak community. Therefore, the mathematical concepts identified in the dance must be understood in the context of the broader culture, in which mathematical reasoning is embedded in collective action, embodied experience and indigenous systems of knowledge.

The *Tumbu Tanah* Dance as an Embodied Spatial System

Our findings suggest that the choreography of the *Tumbu Tanah* Dance constitutes a highly organized spatial system in which movement, rhythm, social interaction, and cultural symbolism are closely interconnected. Rather than functioning solely as a performative or aesthetic activity, the dance creates a dynamic spatial environment through which participants continuously negotiate position, direction, and collective coordination. In this sense, the dance can be understood as an embodied spatial system in which cultural knowledge is expressed through bodily movement and shared participation.

Within the Arfak community, the *Tumbu Tanah* Dance is widely recognized as a “snake dance” because many of its movement patterns resemble the motion of a serpent winding through forests, encircling trees, or traversing mountainous landscapes. This imagery is deeply embedded in local cultural narratives and provides an important conceptual framework for understanding the spatial organization of the choreography. The serpent metaphor is not merely descriptive; it also reflects broader cultural meanings related to continuity, collective movement, adaptability, and interconnectedness within the community.

Field observations revealed several recurring choreographic structures that appeared consistently across performances. These included linear formations (*jey/srem*), semi-circular formations (*ikrop*), full circular formations (*nimot*), as well as serpentine and spiral transitions linking one formation to another. Although these configurations may initially appear as artistic arrangements designed for visual effect, our observations indicate that they represent culturally regulated spatial structures governed by rhythm, social relationships, leadership patterns, and symbolic meanings transmitted across generations.

The movement from one formation to another was performed in a highly coordinated manner. Dancers collectively adjusted their positions while maintaining rhythmic synchronization, relative spacing, and group cohesion. Such transitions generated a variety of geometric configurations that emerged dynamically throughout the performance. We found that dancers continuously monitored the positions of surrounding participants and modified their movements, accordingly, allowing the overall structure of the formation to be preserved despite

ongoing spatial transformations. These observations suggest the presence of sophisticated collective spatial reasoning embedded within the cultural practice of the dance.

A particularly prominent feature of the choreography involved rhythmic foot-stamping movements, locally associated with *bihim ifiri kai* cut. According to participants and cultural elders, these synchronized movements symbolize the relationship between humans and the earth, expressing respect for ancestral land and reinforcing communal bonds among performers. The repeated impact of dancers' feet on the ground created a collective bodily resonance that many participants described metaphorically as representing the "heartbeat of the Arfak land." From an ethnomathematical perspective, these rhythmic patterns also contributed to the temporal and spatial regularity of the performance, providing a common reference structure that guided collective movement.

The interaction between rhythm and spatial organization generated a rich array of geometric relationships. Throughout the dance, participants formed, maintained, and transformed spatial configurations while preserving relative positions and coordinated movement patterns. These practices gave rise to observable mathematical structures involving alignment, spacing, symmetry, circularity, directional movement, and geometric transformation. Importantly, such mathematical relationships were not expressed through formal symbols or explicit mathematical language. Instead, they emerged through embodied action and collective participation, illustrating how mathematical ideas can be embedded within cultural practices and transmitted through performance.

The following sections examine these spatial configurations in greater detail. Beginning with the *jey/srem* linear formation, we explore how specific dance structures embody mathematical concepts related to geometry, measurement, spatial organization, and transformational movement while simultaneously reflecting the cultural values and social relationships of the Arfak people.

Spatial Interpretation of the *Jey/Srem* Linear Formation in the *Tumbu Tanah* Dance

One of the most prominent spatial configurations observed in the *Tumbu Tanah* Dance is the *jey/srem* formation, in which dancers arrange themselves in elongated linear patterns that resemble the movement of a snake. This formation is characterized by a sequential arrangement of dancers who move collectively while maintaining relatively consistent spacing between one another. Based on field observations, dancers continuously adjusted their positions to preserve the integrity of the formation during movement, allowing the group to perform synchronized transitions while maintaining overall spatial coherence. Such configurations demonstrate that the choreography is not merely an aesthetic arrangement but also a structured spatial system governed by collective coordination and shared movement conventions.

Figure 1 presents a field documentation photograph together with a reconstructed spatial interpretation of the *jey/srem* formation. The visual evidence illustrates how dancers are organized along an approximately straight pathway while maintaining coordinated rhythm and movement. Although the formation appears relatively simple from a performance perspective,

closer analysis reveals a number of spatial relationships that can be interpreted through mathematical concepts associated with geometry, measurement, and spatial organization.

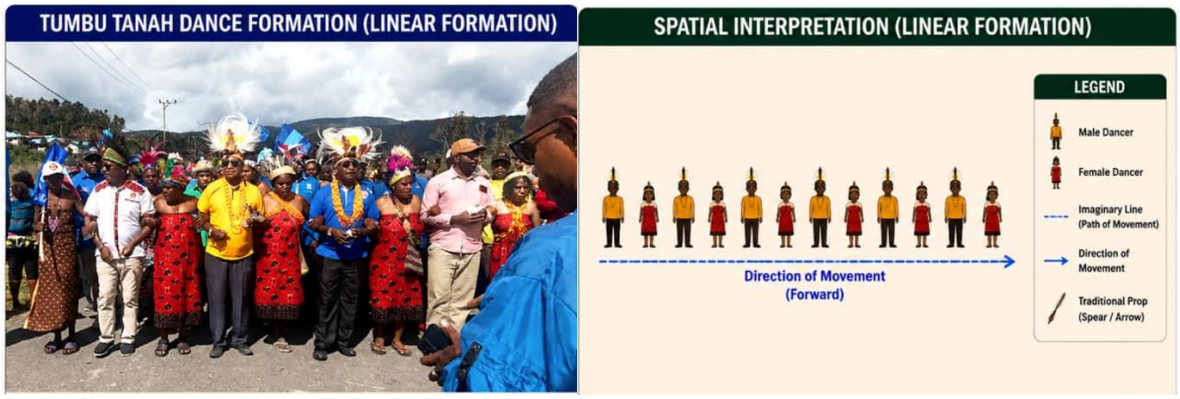

Figure 1. *Tumbu Tanah* Dance in a Linear formation and its spatial interpretation

The field documentation shows male and female dancers positioned in a continuous sequence rather than in strictly segregated groups. In many cases, dancers appear in alternating or semi-alternating arrangements, producing a visually balanced structure while reinforcing the collective nature of the performance. Interviews with cultural practitioners suggest that such arrangements symbolize cooperation, unity, and mutual dependence among community members. Consequently, the linear formation functions not only as a physical arrangement of bodies in space but also as a cultural representation of social harmony within Arfak society.

From a mathematical perspective, the *jey/srem* formation can be modeled as a linear geometric structure consisting of a sequence of ordered points distributed along an imaginary line. The reconstructed spatial model illustrates how individual dancers occupy positions that are organized according to a common orientation and direction of movement. Although the dancers do not intentionally construct a mathematical model, we found that their movement patterns embody principles of alignment, spacing, and positional regularity. The imaginary line represented in the model serves as a conceptual reference pathway that guides collective movement and helps preserve the coherence of the formation.

A particularly notable characteristic of the formation is the consistency of spacing between adjacent dancers. Field observations revealed that participants continuously regulated their interpersonal distances while moving. This practice generated a series of approximately equal intervals along the linear pathway. Such regular spacing contributes to the visual stability of the formation and may be interpreted mathematically as a sequence of ordered points separated by relatively uniform distances. The maintenance of these intervals suggests an intuitive understanding of proportionality and spatial coordination within collective movement systems.

For example, when approximately ten dancers formed a straight-line configuration with an average spacing of one meter between adjacent individuals, the total length of the formation approached nine meters. Although such measurements are only approximate, they provide a

useful illustration of how spatial relationships emerge within the choreography. These configurations enabled the emergence of several mathematical concepts, including line segments, distance measurement, spatial intervals, and ordered point arrangements. The formation therefore provides a tangible representation of geometric relationships that are enacted through movement rather than expressed through formal notation.

The linear arrangement also exhibits a clear directional orientation. As dancers move collectively along a common pathway, the entire formation advances while preserving its overall structure. This coordinated displacement may be interpreted as an example of translational movement. When the formation progresses forward, each dancer undergoes a similar displacement relative to his or her initial position, allowing the group to move as a coherent unit. Although participants may not conceptualize their actions in formal mathematical terms, the observed movement pattern closely resembles the geometric concept of translation, in which an object changes position while maintaining its shape and orientation.

Furthermore, the recurring arrangement of male and female dancers introduces an additional layer of spatial regularity. The repeated alternation of dancer types generates recognizable patterns that can be interpreted mathematically as ordered sequences. Such repetition contributes to visual harmony while simultaneously reflecting cultural values concerning balance, reciprocity, and social cohesion. In this sense, the formation embodies both mathematical regularity and cultural meaning.

The *jey/srem* formation also highlights the collective nature of spatial reasoning within the dance. Rather than emphasizing individual performance, the choreography requires dancers to continually monitor and adjust their positions in relation to neighboring participants. Through these local interactions, the group maintains the alignment and stability of the entire formation. From a systems perspective, the formation functions as a dynamic spatial network in which coordinated individual actions contribute to the preservation of global order. This collective regulation reflects both sophisticated spatial awareness and deeply embedded cultural practices of cooperation.

Taken together, the evidence suggests that the *jey/srem* formation embodies a rich set of geometric and spatial relationships. Concepts such as line segments, distance, proportional spacing, ordered arrangements, directional orientation, and translational movement emerge naturally through the choreography and collective coordination of dancers. We argue that these spatial relationships demonstrate how mathematical ideas can be embedded within cultural performance practices and expressed through embodied action rather than formal symbolic representation. Consequently, the *Tumbu Tanah* Dance provides a compelling example of Indigenous mathematical knowledge, illustrating how the Arfak people construct, maintain, and transmit spatial understanding through movement, rhythm, and social interaction.

Spatial Interpretation of the *Ikrop* and *Nimot* Semi-Circular and Circular Formations (Formation in the *Tumbu Tanah* Dance)

The *ikrop* and *nimot* formations revealed more complex geometric relationships. In circular formations, dancers arranged themselves around a central space while maintaining rhythmic synchronization and equal interpersonal spacing.

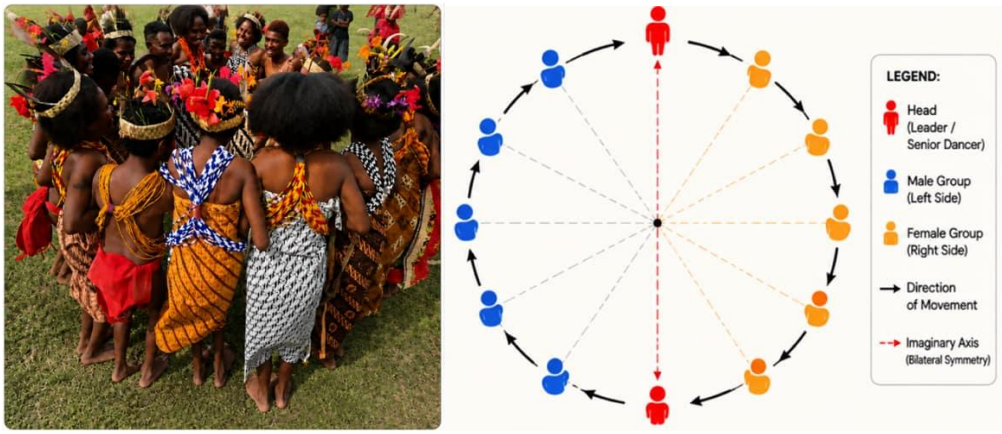

Figure 2. First example of the *Tumbu Tanah* Dance in a circular formation and its spatial interpretation

As illustrated in Figure 2 and 3, the circular formation of the *Tumbu Tanah* Dance creates a spatial arrangement that can be interpreted through several geometric relationships. Although the dancers do not explicitly refer to formal mathematical concepts, we found that the organization of movement and positioning naturally gives rise to structures associated with circumference, radius, diameter, symmetry, and rotational positioning.

Figure 3. Second example of the *Tumbu Tanah* Dance in a circular formation and its spatial interpretation

The circular formations in the *Tumbu Tanah* Dance served not only as spatial arrangements that coordinated the movements of dancers but also carried important social and cultural meanings. In the Arfak community, the circle is understood as a symbol of unity,

continuity, equality, solidarity, and collective strength that brings community members together within a harmonious whole. Our study suggests that these circular formations function beyond their practical role in organizing movement. Rather, they reflect values that are deeply embedded in community life and transmitted across generations. Therefore, we argue that the circular formations should not be viewed merely as geometric configurations, but also as visual representations of the social values that shape and sustain Arfak cultural traditions.

This cultural interpretation was further supported by interviews with the dancers. They explained that once the circular formation had been established, participants were able to dance and jump together for extended periods without experiencing significant fatigue. We found that this experience was understood by the dancers as more than a consequence of physical endurance alone. Rather, the circular formation appeared to foster a sense of shared energy and collective engagement that strengthened group cohesion throughout the performance.

Our study suggests that the circle contributes not only to spatial organization but also to the development of social and psychological dynamics that sustain participation during the dance. In this context, the dancers' endurance is interpreted not merely as an individual physical capacity, but as an expression of collective strength emerging from social interaction, mutual support, and a shared sense of community. We therefore argue that the circular formation functions simultaneously as a geometric arrangement and as a social mechanism through which communal solidarity is experienced and reinforced.

Taken together, these findings suggest that the circle in the *Tumbu Tanah* Dance can be understood as a tangible representation of the principle of collectivism within Arfak society. We found that the circular structure reinforces values of togetherness, mutual support, and shared responsibility that form an important foundation of community life. Beyond its role in organizing movement, the circle appears to embody social relationships and cultural understandings that emphasize cooperation and collective participation. Our study further indicates that the circular form creates a sense of equality among participants, as no single position is symbolically more dominant than another. Each dancer occupies an equivalent place within the formation, reflecting the cultural belief that every individual is an important member of the community. We therefore argue that the circle functions not only as a spatial arrangement but also as a symbolic expression of social inclusion, equality, and collective identity within Arfak cultural traditions.

In addition to its strong cultural significance, the circular formation also reveals the presence of mathematical ideas that are implicitly embedded within cultural practice. From a geometric perspective, the pattern formed by the dancers demonstrates principles of circular geometry and proportional spatial organization. We found that the arrangement of dancers creates a structured spatial pattern in which positions are distributed in a relatively balanced and coordinated manner around a common center.

Although the dancers do not employ formal mathematical terminology, the spatial regularities observed in the formation reflect a practical understanding of geometric relationships. Our study suggests that this understanding is developed through participation in cultural traditions rather than through formal mathematical instruction. Through repeated

practice and intergenerational transmission, community members learn how to organize movement, maintain spacing, and preserve the overall structure of the formation. We therefore argue that the circular formation provides an example of how mathematical thinking can emerge and be sustained within cultural activities, where geometric principles are enacted in practice even when they are not explicitly articulated in mathematical language.

Within the circular formation, each dancer occupies a specific position along the circumference of the circle, maintaining a relatively uniform distance from neighboring dancers. We found that this balanced spatial distribution enables participants to move synchronously while minimizing physical interference and maintaining the rhythm of the group performance. The arrangement supports coordinated movement and helps preserve the overall stability of the formation throughout the dance.

From a mathematical perspective, this pattern reflects principles of proportional spatial organization. The relatively equal spacing between dancers suggests an implicit division of space in which each participant is allocated a comparable area for movement within an organized system. Our study indicates that such spatial regularity contributes to both the aesthetic coherence and functional effectiveness of the performance. We therefore argue that the circular formation demonstrates how culturally transmitted practices can embody mathematical ideas related to symmetry, spatial distribution, and proportional organization, even in the absence of formal mathematical representation.

The geometric relationships embedded in the formation can be interpreted through a basic principle of circle geometry, namely the relationship between a circle's circumference and its radius. This relationship is expressed as:

$$C = 2\pi r \tag{1}$$

where (C) represents the circumference of the circle and (r) represents its radius.

We used this geometric model as an analytical tool to examine the spatial characteristics of the dance formation. Our study suggests that the size of the circular formation can be estimated from the number of dancers and the observed spacing between adjacent participants during the performance. When the distance between dancers remains relatively constant, an increase in the number of participants leads to a larger circumference, which in turn requires a proportional increase in the radius of the circle. In this way, the overall size of the formation expands while maintaining the balanced spatial arrangement necessary for coordinated movement.

Importantly, we do not suggest that the dancers consciously apply formal geometric formulas when performing. Rather, we argue that the spatial organization observed in the Tumbu Tanah Dance can be interpreted through mathematical modelling, revealing geometric relationships that are embedded within cultural practice and sustained through generations of collective experience.

Based on field observations, the circular formation in one of the performances was estimated to have a radius of approximately 3 meters. Using the geometric model introduced above, the circumference can be calculated as follows:

$$C = 2 \text{ x } 3.14 \text{ x } 3 \quad (2)$$

Thus, the circumference of the formation is approximately 18.85 meters, which can be rounded to 19 meters. This calculation suggests that the outer boundary of the dance formation extends over a path of roughly 19 meters.

Assuming that 19 dancers are positioned evenly along the circumference, each dancer would occupy approximately one meter of space. We found that this relatively uniform distribution of space provides sufficient room for individual movement while preserving the integrity of the collective formation. Such spacing appears to support synchronized movement, maintain the balance of the circular arrangement, and contribute to the overall stability of the performance. It is important to note that these calculations are not intended to imply that dancers consciously measure or construct the formation using formal geometric procedures. Rather, our study uses mathematical modelling as an analytical lens to better understand the spatial organization embedded within the dance. We argue that the observed regularity of spacing and movement reflects a practical and culturally transmitted understanding of spatial relationships that has developed through long-standing communal practice.

This analysis suggests that cultural practices can serve as valuable empirical contexts for understanding geometric concepts in meaningful and situated ways. Through observations of dancers' positions, interpersonal spacing, and the overall size of the formation, mathematical ideas such as radius, diameter, circumference, proportion, and spatial distribution can be identified and explored without diminishing the cultural meanings embedded in the practice itself.

We found that the circular formation provides a concrete example of how mathematical relationships can be observed within everyday cultural activities. Rather than treating mathematics as a body of abstract and decontextualized knowledge, our study illustrates how geometric concepts can emerge from real-world experiences that are familiar and culturally significant to community members. In this sense, cultural practices offer opportunities for connecting mathematical ideas to observable phenomena and lived experiences.

We therefore argue that culture can function as an authentic context for mathematical learning and interpretation. The *Tumbu Tanah* Dance demonstrates that mathematical concepts are not necessarily separate from cultural life; instead, they may be embedded within social practices, spatial arrangements, and collective activities that have been developed and transmitted across generations. Such findings support broader ethnomathematical perspectives that view mathematics as a human activity expressed in diverse cultural forms and contexts.

More importantly, these findings indicate that mathematical knowledge in the *Tumbu Tanah* Dance is not expressed through formal symbols, formulas, or procedural calculations. Rather, it appears as embedded mathematical knowledge that is enacted through the spatial practices of the community. We found that dancers collectively construct and maintain stable geometric formations through coordinated movement, spatial awareness, and culturally transmitted rules that guide participation in the dance.

Our study suggests that the geometric regularity observed in the circular formation emerges from shared cultural practices rather than from explicit mathematical instruction.

Through repeated participation and intergenerational transmission, community members learn how to position themselves, regulate interpersonal spacing, and preserve the overall structure of the formation. In this way, mathematical ideas become embodied in practice and are reproduced through collective action.

We argue that this phenomenon is consistent with ethnomathematical perspectives, which view mathematics as a human activity that develops within specific social and cultural contexts rather than as a purely abstract and universal system of knowledge. As noted by D'Ambrosio, (1985) and further elaborated by Rosa and Orey, (2016), mathematical thinking can be embedded in cultural practices, social interactions, and locally developed ways of organizing experience. The *Tumbu Tanah* Dance provides a compelling example of this perspective, demonstrating how geometric reasoning can be enacted and sustained through cultural participation even when it is not formally articulated in mathematical language.

Therefore, the circular formation in the *Tumbu Tanah* Dance can be understood as a meeting point between cultural and mathematical dimensions. On the one hand, the circle represents collective identity, social solidarity, and the values of togetherness that are central to Arfak community life. On the other hand, it embodies a geometric structure through which mathematical concepts such as circumference, radius, diameter, proportion, symmetry, and spatial organization can be explored and interpreted.

We found that these cultural and mathematical dimensions are not separate elements but are closely intertwined within the practice of the dance. The same formation that conveys cultural meanings of unity and collective responsibility also exhibits spatial regularities that can be analyzed using geometric principles. This dual character highlights the potential of cultural practices to serve as both carriers of social values and contexts for mathematical understanding.

Our study therefore argues that local cultural practices should not be viewed solely as social heritage or artistic expression. They may also represent rich sources of mathematical knowledge that emerge from lived experience and collective participation. The *Tumbu Tanah* Dance illustrates how cultural traditions can provide meaningful contexts for exploring mathematical ideas while preserving their cultural significance. Such findings support the development of mathematics education that is contextualized, culturally responsive, and grounded in the knowledge systems of local communities. In this sense, integrating cultural practices into mathematics education may help learners connect abstract mathematical concepts with authentic experiences that are relevant to their social and cultural worlds.

Rotational Geometry and Geometric Transformations in the *Tumbu Tanah* Dance

The *ikrop* and *nimot* formations revealed more complex geometric relationships. In circular formations, dancers arranged themselves around a central space while maintaining rhythmic synchronization and equal interpersonal spacing. One important finding from our study concerns the presence of various forms of geometric transformation embedded in the changing positions and formations of dancers throughout the performance. Unlike formal geometric representations, which are typically expressed through symbols, diagrams, or mathematical notation, transformations in the *Tumbu Tanah* Dance emerge implicitly through bodily movements, shifts in position, and the collective reorganization of space by the dancers. We

found that these transformations are not consciously articulated as mathematical concepts by participants; nevertheless, they are consistently enacted through coordinated movement patterns. Our study suggests that the cultural practices of the Arfak people embody not only static geometric structures but also dynamic forms of geometry that evolve through social interaction and collective movement. We argue that these findings broaden our understanding of how mathematical ideas can be embedded within cultural activities and expressed through lived practices rather than formal representations.

During field observations, we found that the dancers consistently moved from one spatial configuration to another while maintaining rhythmic coordination and the overall coherence of the formation. These transitions revealed patterns that can be interpreted through concepts commonly associated with transformational geometry in modern mathematics. In particular, the movements reflected elements of translation, rotation, spatial transformation, and directional symmetry. Although these mathematical ideas were not explicitly identified by the dancers, our observations suggest that they were embedded in the collective organization of movement and space throughout the performance.

Figure 4 presents an example of field documentation illustrating a linear formation in the *Tumbu Tanah* Dance together with a mathematical interpretation of the dancers' social organization. The figure shows how participants are arranged in a coordinated linear structure while maintaining collective movement and spatial order. From a mathematical perspective, this formation provides a useful representation of how spatial relationships and geometric patterns are embedded within the social practices of the dance.

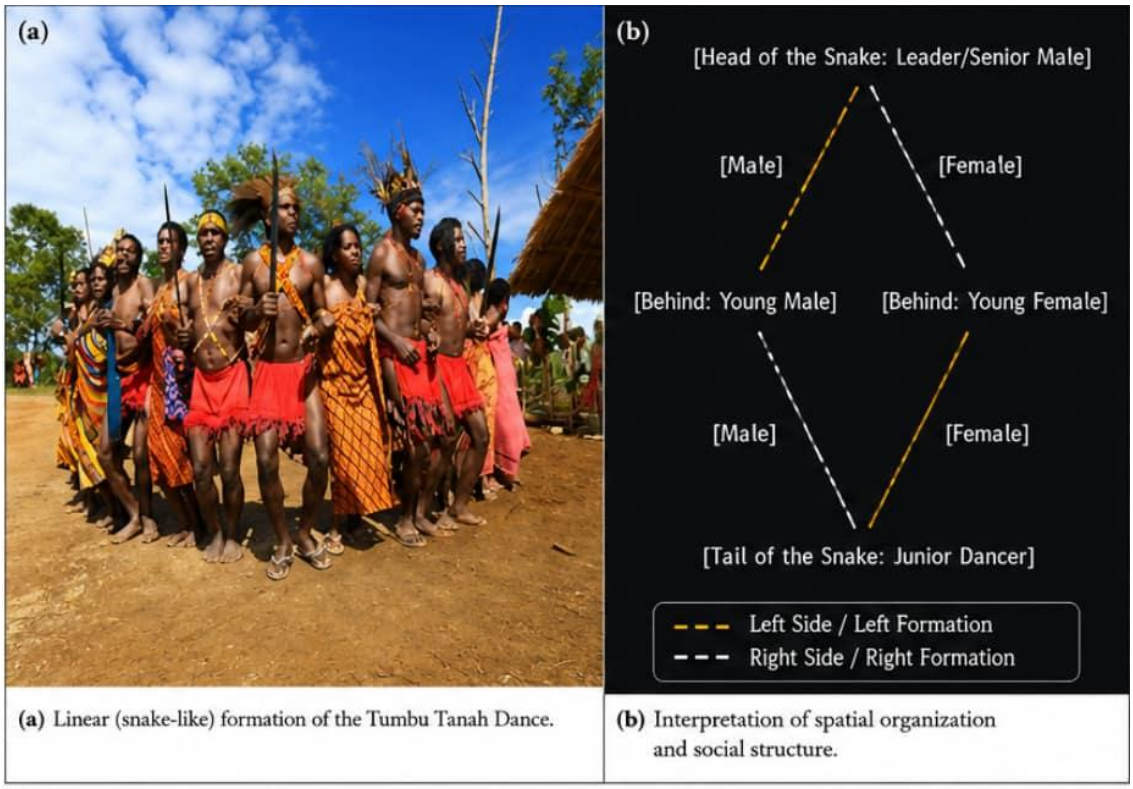

Figure 4. Snake-like formation of the *Tumbu Tanah* Dance and Representation of the Spatial Structure of the Dancer

Based on our observations and interviews with cultural elders, this formation resembles a snake-like movement pattern that is widely recognized as a distinctive feature of the *Tumbu Tanah* Dance. At the front of the formation is a leader or senior dancer who assumes the role of the "head of the snake," while the remaining dancers follow similar movement patterns, creating an elongated sequence that extends toward the "tail of the snake." We found that this structure functions as more than a physical arrangement of bodies in space. Rather, it reflects important aspects of Arfak social organization, where experience, seniority, and leadership are highly valued within communal life. The formation therefore carries both spatial and cultural significance, illustrating how movement patterns can simultaneously express social relationships and collective identity.

From a mathematical perspective, this arrangement demonstrates a form of spatial regularity that can be interpreted as a geometric pathway with a particular orientation. We found that each dancer maintained a relatively consistent distance from the dancer ahead, producing a repeated pattern of movement along the trajectory of the formation. In this sense, when the lead dancer moved in a given direction, the other dancers followed through similar displacements, allowing the spatial relationships among participants to remain largely unchanged. We argue that this movement pattern provides an intuitive representation of translation in geometry, where objects shift from one position to another while preserving their relative arrangement and overall structure.

In addition to translation, the snake-like movement pattern also gives rise to rotational transformations when the group changes direction to form curves, circles, or spiral-like structures. During several segments of the performance, we observed the lead dancer turning around a particular area, followed progressively by the other members of the group. As a result, the overall trajectory of the formation developed into curved patterns that resembled spirals or recursive pathways. From a mathematical perspective, these movement patterns can be interpreted as a combination of translation and rotation, producing changes in orientation while preserving the coherence and structural integrity of the original formation. We argue that such transformations demonstrate how dynamic geometric relationships are embedded within the choreography and enacted through coordinated collective movement.

Our video analysis showed that the transition from a linear formation to a circular formation was not performed randomly. Rather, each dancer adjusted his or her position in relation to the surrounding dancers, resulting in a coordinated reorganization of space. We found that these adjustments occurred in a systematic manner, allowing the group to maintain its overall coherence while gradually transforming the structure of the formation. The ability to preserve group organization throughout this process suggests the presence of a shared spatial understanding that has been developed and transmitted through cultural practice and intergenerational learning. We argue that this collective spatial knowledge plays an important role in sustaining the continuity of the dance and enabling complex transformations to be performed without formal instructions or written representations.

Furthermore, the two-sided structure shown in Figure 4 reveals a form of balance between the male and female groups. The arrangement of these groups creates a pattern that resembles

bilateral symmetry along an imaginary axis extending from the head to the tail of the formation. Although this symmetry is not always exact in the sense of formal Euclidean geometry, we found that the overall pattern reflects a consistent effort to maintain spatial balance throughout the performance. From a mathematical perspective, this arrangement illustrates an intuitive expression of symmetry, while from a cultural perspective it reflects values of harmony, coordination, and collective order. We argue that the coexistence of these mathematical and cultural dimensions highlights how spatial organization in the *Tumbu Tanah* Dance serves both aesthetic and social functions.

The snake-like movement pattern also exhibits recursive and cyclical characteristics. Based on our observations and discussions with cultural elders, each part of the symbolic snake represents the continuity of relationships across generations within Arfak society. The head determines the direction of movement, while the dancers behind follow similar movement patterns in a repeated sequence. We found that this structure reflects a close connection between mathematical ideas and cultural meaning. From a mathematical perspective, it illustrates concepts such as pattern repetition and iterative transformation, where a sequence of movements is reproduced across different positions within the formation. At the same time, the pattern carries cultural significance by symbolizing social continuity, collective identity, and the transmission of knowledge from one generation to the next. We argue that these intertwined mathematical and cultural dimensions demonstrate how recurring movement patterns can serve as both organizational mechanisms and meaningful cultural expressions.

These findings suggest that geometry in the *Tumbu Tanah* Dance is expressed not only through static shapes or spatial patterns but also through dynamic transformations that emerge during movement. We found that mathematical ideas are embedded in the performance itself, where concepts such as translation, rotation, symmetry, and spatial organization are enacted through coordinated bodily actions rather than represented through formal symbols or notation. In this sense, mathematics appears as an embodied practice, closely intertwined with cultural activities and social interaction.

Our study therefore suggests that the *Tumbu Tanah* Dance can be understood as a form of local mathematical knowledge that reflects how the Arfak people construct, maintain, and transmit spatial understanding through movement, rhythm, and collective participation. We argue that this example broadens conventional views of mathematics by showing that mathematical thinking can be expressed and preserved within cultural practices, even in contexts where formal mathematical language is not explicitly used.

These findings further support the argument that local cultural practices can provide a rich foundation for the development of contextualized approaches to teaching transformational geometry. Through the exploration of movement patterns in the *Tumbu Tanah* Dance, students may engage with formal mathematical concepts while also gaining insights into cultural values, collective identity, and the relationship between people and their environment. We argue that such connections can make mathematical learning more meaningful by linking abstract geometric ideas to lived cultural experiences.

Our study also suggests that integrating ethnomathematics and transformational geometry offers benefits beyond mathematics education alone. In addition to supporting conceptual understanding, this approach may help promote cultural awareness and appreciation of Indigenous knowledge systems. In the context of the Arfak community, the use of *Tumbu Tanah* Dance as a learning resource has the potential to contribute to the preservation and transmission of cultural heritage while creating opportunities for culturally responsive and locally relevant mathematics education.

Numerical Structures and Rhythmic Coordination in the *Tumbu Tanah* Dance

Beyond its spatial and geometric characteristics, the *Tumbu Tanah* Dance also reveals sophisticated forms of numerical reasoning embedded within its rhythmic organization and participation structures. The findings indicate that numerical concepts emerge naturally through collective movement, temporal coordination, and social arrangements, demonstrating that mathematical thinking is deeply intertwined with cultural practice rather than existing solely as formal symbolic knowledge.

Numerical Organization of Dancers

Another important mathematical dimension identified in the *Tumbu Tanah* Dance concerns the numerical organization of participants within the performance. Field observations and participant interviews revealed that *Tumbu Tanah* performances typically involve a minimum of ten dancers and may expand into considerably larger communal formations involving representatives from multiple clans, villages, and kinship groups. The number of participants and their spatial arrangement are not arbitrary decisions but are carefully regulated by customary traditions, social hierarchies, kinship affiliations (*keret*), and the specific ceremonial purposes of the performance.

Participants consistently emphasized that the composition of the dance group reflects the social structure of the Arfak community. Dancers are often organized according to clan membership, age categories, gender roles, or designated ceremonial responsibilities. In several observed performances, elders occupied positions along the outer sections or leading segments of the formation, while younger participants were positioned toward the center or intermediate sections. These arrangements served not only ceremonial and symbolic purposes but also generated observable patterns of numerical organization and structured participation.

From an ethnomathematical perspective, such participation structures reveal embedded forms of quantitative reasoning that govern collective coordination. The allocation of dancers across different social groups demonstrates implicit applications of several mathematical concepts, including grouping and classification systems, numerical partitioning, proportional distribution, set relationships and subset formation, balanced allocation of participants, and numerical equivalence and representation.

The organization of dancers can be interpreted mathematically through the concept of set partitioning. Within the Arfak cultural system, kinship relations are organized through a number of recognized clans (*keret*), which constitute the fundamental social units governing communal participation. Community informants explained that the Arfak people traditionally recognize

nineteen major clans that collectively structure social relationships, customary responsibilities, and ceremonial participation. Consequently, the entire group of dancers participating in a *Tumbu Tanah* performance can be represented as a universal set (D), while individual clan groups may be represented as subsets $K1, K2, K3, \ldots, K19$, such that:

$$D = K_1 \cup K_2 \cup K_3 \cup \ldots \cup K_{19} \quad (3)$$

where each subset corresponds to one of the nineteen Arfak clans or to a specific social category participating in the ceremony. Although not all clans are necessarily represented in every performance, the mathematical model illustrates how the collective dance formation emerges through the integration of multiple social groups into a unified cultural structure while preserving the identity and representation of each clan. From an ethnomathematical perspective, this organizational pattern reflects principles of set theory, classification, partitioning, and collective aggregation embedded within Indigenous social practices.

Furthermore, the participation of multiple clans within a single performance demonstrates how numerical organization functions as a mechanism for maintaining social cohesion and ceremonial balance. The integration of these clan-based subsets into a larger communal whole mirror the mathematical relationship between subsets and a universal set, illustrating how cultural systems can embody sophisticated forms of quantitative reasoning without the explicit use of formal mathematical notation.

In addition to classification, proportional reasoning was evident in the effort to maintain balanced representation among participating clans. Community members explained that no single clan should dominate the performance, particularly during ceremonies intended to symbolize communal unity and social harmony. Consequently, organizers often seek to ensure relatively proportional participation among groups. For example, if a performance involves 30 dancers representing three clans, an approximately balanced distribution may allocate ten dancers to each clan. Although such arrangements are not calculated through formal mathematical procedures, they nevertheless reflect intuitive forms of ratio, proportion, and equitable distribution.

These findings suggest that numerical reasoning within the *Tumbu Tanah* Dance extends beyond simple counting. Numerical structures function as mechanisms for maintaining social balance, ceremonial legitimacy, and collective representation. The mathematical principles embedded in these practices are inseparable from the cultural values that guide participation and community relationships.

From a broader ethnomathematical perspective, the numerical organization observed in the *Tumbu Tanah* Dance illustrates how mathematical thinking can emerge naturally within social and cultural practices. Concepts commonly associated with formal school mathematics, such as sets, subsets, partitioning, proportionality, classification, and quantitative balance, are enacted through communal participation rather than expressed through symbolic notation. This finding supports the view that mathematical knowledge is culturally situated and can be embodied within traditional practices long before it is formalized in academic mathematics. Consequently, the *Tumbu Tanah* Dance provides a valuable context for demonstrating how

Indigenous cultural systems preserve sophisticated forms of mathematical reasoning that contribute simultaneously to social cohesion, cultural continuity, and collective identity.

Rhythmic Periodicity and Temporal Coordination

A particularly significant mathematical dimension emerged from the rhythmic structure of the dance. Participants consistently described the *Tumbu Tanah* Dance as being inseparable from traditional songs, chants, and percussion patterns that regulate collective movement. The repetitive stepping sequences coordinated foot stamping (*bihim ifiri kai cut*), and recurring directional changes generate observable patterns of temporal regularity.

These recurring movement cycles can be interpreted mathematically as periodic motion characterized by repetition over fixed time intervals. The relationship between frequency and period can be represented as follows:

$$f = \frac{1}{T} \tag{4}$$

where:

- f represents the frequency of rhythmic repetition;
- T represents the duration of one complete movement cycle (period).

The relationship between the frequency of rhythmic repetition and the duration of one complete movement cycle is presented in Figure 5.

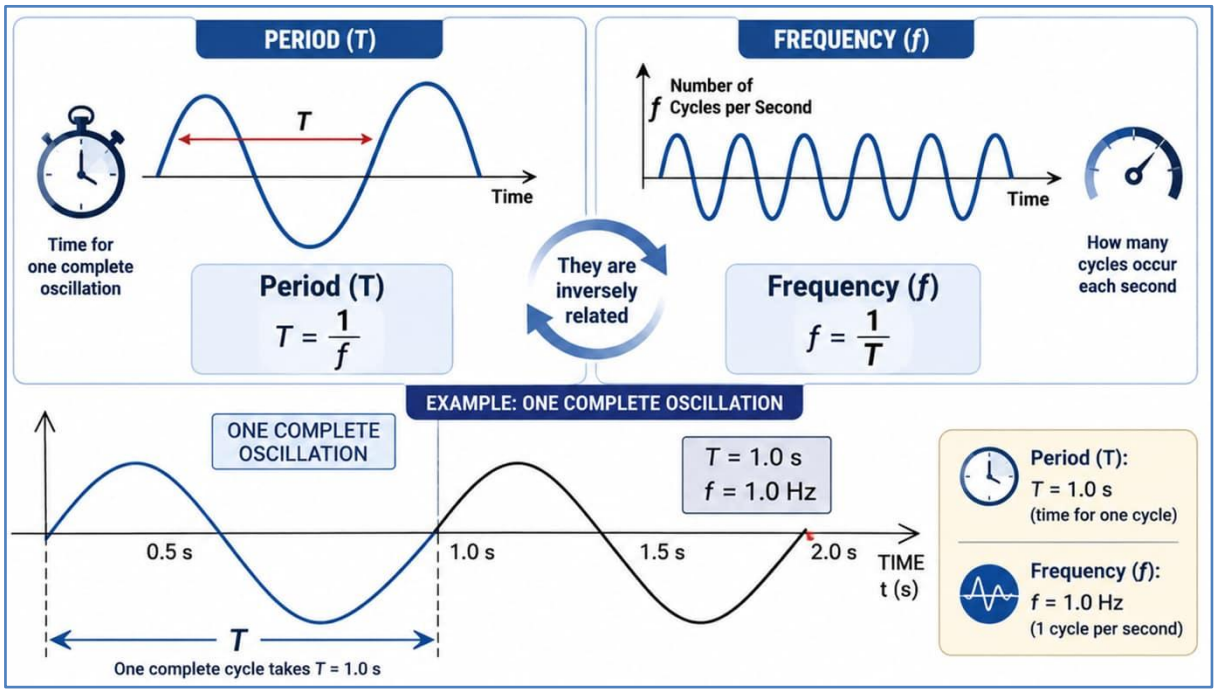

Figure 5. Mathematical Representation of Rhythmic Periodicity in the *Tumbu Tanah* Dance

Figure 5 provides a conceptual representation of this relationship by illustrating how a complete oscillatory cycle corresponds to a specific temporal interval. In the context of the

Tumbu Tanah Dance, a movement cycle may be understood as the time required for dancers to complete a recurring sequence of coordinated actions before returning to an equivalent spatial and rhythmic position. The figure demonstrates that rhythm can be analyzed not only as a musical phenomenon but also as a measurable temporal structure characterized by periodic repetition.

The inverse relationship between period and frequency is further illustrated in Figure 6. As the duration of a movement cycle increases, the number of cycles that can occur within a given time interval decreases. Conversely, when movement cycles become shorter, the frequency of repetition increases. Mathematically, this relationship indicates that frequency and period are inversely proportional. For example, if one complete movement cycle requires one second, the frequency equals one cycle per second ($f = 1\ Hz$). If the same movement pattern is performed three times within one second, the frequency increases to three cycles per second ($f = 3\ Hz$), while the period decreases to approximately 0.33 seconds.

The conceptual relationship represented in Figures 5 and 6 closely corresponds to the rhythmic organization observed during performances. Although dancers do not explicitly calculate periods or frequencies, they collectively maintain stable temporal intervals through continuous auditory and kinesthetic feedback. Traditional songs, drum patterns, vocal chants, and mutual observation function as synchronizing mechanisms that enable dancers to preserve a common rhythm over extended periods of time. Consequently, temporal consistency is achieved through embodied cultural practice rather than through formal measurement instruments.

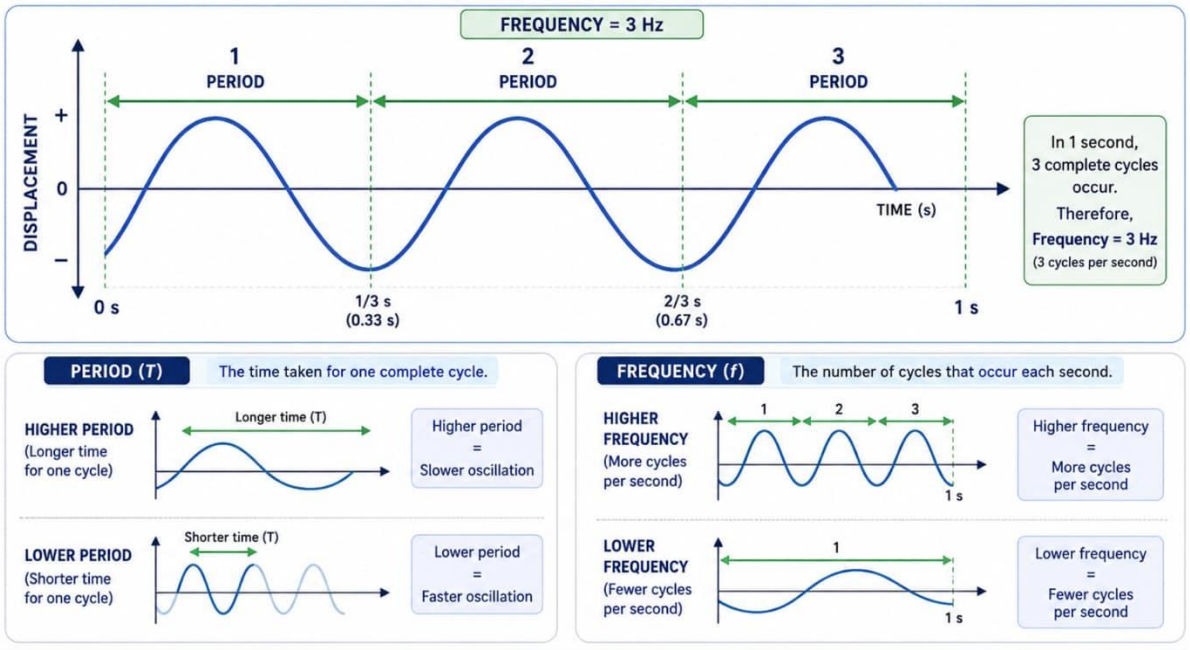

Figure 6. Illustration of the Inverse Relationship Between Period (T) and Frequency (f) in Periodic Motion

Field observations indicated that *Tumbu Tanah* performances commonly lasted between 35 and 50 minutes and consisted of repeated cycles of stepping, rotation, directional transformation, and formation changes. Despite the considerable duration of these performances, dancers demonstrated remarkable temporal stability and collective synchronization. The ability to sustain repeated movement cycles while maintaining rhythmic coherence suggests an implicit understanding of temporal regularity, cyclical repetition, and frequency control.

From an ethnomathematical perspective, these findings reveal that mathematical ideas related to periodicity are embedded within cultural performance practices. Rhythm in the *Tumbu Tanah* Dance functions simultaneously as a cultural mechanism and a mathematical structure. Culturally, rhythmic patterns facilitate collective participation, reinforce social cohesion, and preserve traditional knowledge. Mathematically, the same patterns embody concepts of period, frequency, repetition, and temporal measurement that are fundamental to the study of periodic phenomena.

Furthermore, the dancers' ability to maintain synchronization over prolonged performances reflects an intuitive form of temporal reasoning. Rather than relying on clocks, numerical calculations, or formal notation, temporal relationships are regulated through shared cultural knowledge, embodied experience, and collective responsiveness to auditory cues. This finding demonstrates how mathematical concepts can exist in implicit and embodied forms within Indigenous cultural practices, reinforcing the central premise of ethnomathematics that mathematical thinking is often embedded in everyday cultural activities rather than expressed exclusively through formal symbolic representations.

Finally, Figures 5 and 6 provide a useful analytical framework for interpreting the rhythmic structure of the *Tumbu Tanah* Dance. The concepts of period and frequency offer mathematical explanations for how dancers achieve collective temporal coordination, while simultaneously revealing the sophisticated forms of embodied mathematical reasoning embedded within Arfak cultural traditions.

Symbolic and Cultural Interpretations of Mathematical Structures

The findings reveal that the mathematical structures identified within the *Tumbu Tanah* Dance cannot be fully understood apart from the cultural meanings that give rise to them. Geometric formations, numerical organization, spatial arrangements, and rhythmic periodicity do not appear as abstract mathematical concepts consciously constructed through formal instruction. Rather, they emerge as embodied forms of knowledge that are deeply embedded within the social, cultural, and ceremonial practices of the Arfak community.

Participants consistently interpreted the various dance formations not merely as choreographic arrangements but as symbolic representations of collective social values. In particular, circular formations (*nimot*) were frequently associated with unity, equality, solidarity, mutual support, and communal identity. One elder explained that "the circle has no dominant head; everyone stands together," illustrating how a geometric configuration simultaneously functions as a social and philosophical statement. Within this interpretation, the

mathematical properties of the circle, such as symmetry, continuity, and equal positioning around a common center, become inseparable from cultural understandings of social cohesion and collective belonging.

From an ethnomathematical perspective, this finding demonstrates how geometric concepts can serve as cultural symbols that communicate shared values and social relationships. The circle is not merely a spatial arrangement of dancers but also a representation of collective identity, where each participant occupies an equivalent position within the ceremonial structure. The mathematical and cultural dimensions therefore coexist within a single symbolic system, reinforcing one another through repeated communal practice.

Similarly, the regulated spacing between dancers reflects both mathematical and cultural considerations. Observations indicated that participants maintained relatively consistent interpersonal distances throughout performances, producing organized geometric patterns that facilitated collective movement and spatial coordination. At the same time, these distances embodied culturally appropriate forms of social interaction, reflecting respect, cooperation, and relational balance among participants. Spatial organization therefore functions simultaneously as a mechanism for choreographic stability and as a cultural expression of social order.

The rhythmic dimension of the dance further illustrates the integration of mathematical and cultural knowledge. Repetitive stepping sequences, synchronized foot stamping (*bihim ifiri kai cut*), coordinated body movements, and recurring musical patterns generate observable periodic structures that can be analyzed mathematically through concepts of frequency, repetition, and temporal regularity. However, community members described these rhythmic practices not simply as techniques for maintaining movement coordination but also as expressions of collective harmony and interconnectedness. Rhythm serves as a medium through which dancers align their movements with one another, reinforcing social unity while simultaneously creating mathematically recognizable patterns of periodic motion.

Beyond facilitating coordination among dancers, rhythmic synchronization was frequently described as symbolizing harmonious relationships among humans, ancestors, and the natural environment. Such interpretations suggest that temporal regularity within the dance carries meanings that extend beyond physical movement. Mathematical order and cultural symbolism become intertwined through the performance itself, creating a holistic system in which numerical regularity, spatial organization, and social values are mutually reinforcing.

The numerical organization of participants likewise reflects this integration of mathematical and cultural structures. Dancers are commonly arranged according to clan affiliations (*keret*), age groups, ceremonial roles, or other socially recognized categories. These arrangements can be interpreted mathematically through concepts such as classification, grouping, set partitioning, and hierarchical organization. Nevertheless, these numerical structures originate from customary social systems rather than from explicit mathematical reasoning. Mathematical relationships emerge as inherent characteristics of the cultural organization itself.

Taken together, these findings indicate that the *Tumbu Tanah* Dance functions as an Indigenous spatial–numerical knowledge system in which geometry, rhythm, movement,

number, and social organization are inseparably interconnected. The mathematical relationships identified in this study are not external analytical categories imposed upon the dance by researchers; rather, they arise organically through cultural practice, collective participation, and intergenerational transmission of knowledge.

More broadly, these findings support central arguments within ethnomathematics that mathematical knowledge is not restricted to formal schooling, symbolic notation, or academic discourse. Instead, mathematical thinking may be embodied, contextual, experiential, and culturally situated. Long before concepts such as geometry, symmetry, periodicity, measurement, and spatial modelling are represented through formal mathematical language, they often exist within traditional cultural practices as practical and meaningful ways of organizing social life. The *Tumbu Tanah* Dance therefore illustrates how Indigenous knowledge systems preserve sophisticated mathematical ideas through performance, ritual, and communal participation, providing valuable insights for culturally responsive mathematics education and the recognition of diverse mathematical epistemologies.

Discussion

The findings of this study provide substantial evidence in support of the central tenet of ethnomathematics, namely that mathematical concepts originate from culturally specific human activities rather than from formal symbolic systems or institutionalized education alone. The *Tumbu Tanah* Dance of the Arfak people show that indigenous cultural practices can embody sophisticated forms of spatial organization, geometric reasoning, rhythmic coordination, numerical structuring and collective measurement, which can be analyzed mathematically while retaining their cultural, social and spiritual significance. This perspective aligns with ethnomathematics scholarship which conceptualizes mathematics as a cultural product shaped by the historical, social and environmental experiences of specific communities (D'Ambrosio, 1985; Rosa & Orey, 2016).

The study identified several mathematical structures within the dance, including linear, circular and semi-circular formations, rotational and translational transformations, rhythmic periodicity, proportional spacing between dancers, and a numerical organization system based on clan affiliations and ceremonial roles. Participants do not consciously express these structures through formal mathematical terminology, equations, or symbolic notation. Instead, they emerge organically through collective participation, intergenerational cultural transmission, and embodied communal practices. Such findings reinforce the ethnomathematical position that mathematics is not confined to formal educational settings, but is deeply embedded in everyday cultural activities and social practices (Ascher, 1991; D'Ambrosio, 1985; Presmeg, 1998).

The results strongly support the theoretical framework proposed by D'Ambrosio (1985), who argued that mathematics should be understood as a system of cultural knowledge developed by human groups in response to their social, environmental and historical circumstances. In the Arfak community, mathematical reasoning is not separate from cultural

life, but is instead integrated into ceremonial performances, social organization, ecological relationships and collective identity. The geometric formations, rhythmic structures and spatial arrangements observed therefore represent culturally embedded mathematical practices rather than abstract exercises detached from lived experience. These findings support contemporary ethnomathematics research which emphasizes that Indigenous knowledge systems are legitimate mathematical epistemologies, rather than merely cultural contexts for illustrating formal mathematics.

Furthermore, the findings align with contemporary embodied cognition theories that emphasize the importance of bodily action, sensory experience, movement and interaction with the environment in developing mathematical understanding. An increasing body of research in mathematics education demonstrates that gestures, bodily movement, spatial manipulation, and physical engagement play an important role in developing mathematical understanding and spatial reasoning (Boonstra & Drieenhuizen, 2023; Tran et al., 2017; Way et al., 2024). The coordinated movements of dancers synchronized stepping patterns, rotational transitions and the collective maintenance of spatial formations illustrate how mathematical cognition can emerge through sensorimotor engagement. Rather than viewing mathematics as a purely symbolic or mental activity, the *Tumbu Tanah* Dance shows that mathematical understanding can be expressed through physical movement and shared participation. In this sense, geometry is not merely represented but performed. Rhythm is not merely counted, but experienced. Spatial relationships are not merely described but continuously negotiated through collective movement. This interpretation aligns with recent research emphasizing the close relationship between embodied action, spatial reasoning, and mathematical cognition.

An important contribution of this study lies in demonstrating the inseparability of mathematical structures and cultural meanings. The circular formations observed in the dance illustrate this relationship particularly clearly. From a mathematical perspective, the formations embody concepts of circular geometry, symmetry, proportional spacing, and spatial organization. From a cultural perspective, however, the same formations symbolize unity, equality, solidarity, collective identity, and social harmony. The circle therefore functions simultaneously as a geometric structure and a cultural metaphor. Similar dual functions were observed in rhythmic coordination, numerical grouping, and spatial positioning, where mathematical regularity and cultural symbolism coexist within a single performative system. This finding supports arguments that ethnomathematical knowledge should not be reduced to identifying mathematical patterns alone but must also be interpreted within broader cultural and symbolic systems of meaning.

The findings also contribute to ongoing discussions regarding the decolonization of mathematics education. Conventional mathematics curricula frequently present mathematical knowledge as universal, culturally neutral, and detached from local ways of knowing. Such approaches may inadvertently marginalize Indigenous epistemologies by positioning Western mathematical traditions as the primary source of legitimate mathematical knowledge. The present study challenges this assumption by demonstrating that Indigenous cultural practices contain rich mathematical ideas that are conceptually sophisticated, socially meaningful, and

educationally valuable. Recognizing these practices as legitimate forms of mathematical knowledge contributes to broader efforts toward epistemic justice, cultural inclusion, and the diversification of mathematical narratives within educational systems. Recent scholarship on decolonizing mathematics education similarly argues that Indigenous knowledge systems should be recognized as valid intellectual traditions capable of enriching mathematics learning and challenging Eurocentric assumptions within curricula.

From an educational perspective, the identified mathematical structures provide culturally relevant contexts for teaching a wide range of mathematical concepts, including geometry, symmetry, transformation, measurement, proportional reasoning, spatial visualization, patterns, and periodic functions. Integrating ethnomathematical contexts such as the *Tumbu Tanah* Dance into classroom instruction may support culturally responsive pedagogy by connecting school mathematics to students' cultural experiences and community knowledge. Research has shown that culturally grounded mathematics education can strengthen conceptual understanding, improve student engagement, and foster positive mathematical identities while simultaneously preserving cultural heritage (Batiibwe, 2024; Rosa & Orey, 2011). For Indigenous students in particular, culturally responsive mathematics learning may help bridge the gap between community knowledge systems and formal educational practices.

Beyond its educational implications, this study also contributes methodologically to ethnomathematics research. Much of the existing literature has focused on relatively static cultural artefacts such as weaving patterns, ornaments, textiles, carvings, and traditional architecture. While such studies have generated important insights into culturally embedded mathematical ideas, dynamic cultural practices remain comparatively underexplored. By examining a traditional dance performance, this study expands the methodological scope of ethnomathematics toward performative and embodied cultural phenomena. The *Tumbu Tanah* Dance reveals that mathematical structures may emerge not only through material artefacts but also through movement, rhythm, coordination, and collective bodily action. This finding aligns with recent reviews highlighting the need to broaden ethnomathematical inquiry beyond static representations toward more diverse forms of Indigenous knowledge expression.

The study also contributes to emerging interdisciplinary conversations involving ethnomathematics, anthropology, Indigenous studies, embodied cognition, spatial reasoning, and mathematics education. Contemporary research increasingly recognizes spatial reasoning as a foundational dimension of mathematical thinking and highlights its relationship with movement, bodily engagement, and cultural practices. The findings suggest that mathematical knowledge should be viewed not merely as a collection of abstract concepts but as a multidimensional cultural practice situated within broader social, ecological, and historical relationships. Such a perspective aligns with contemporary calls for more holistic and pluralistic understandings of knowledge that acknowledge the diversity of human mathematical experiences across cultures.

Nevertheless, several limitations should be acknowledged. First, the spatial measurements and geometric interpretations presented in this study were derived primarily from ethnographic observations, field documentation, participant interviews, and visual

analysis of dance formations. Although these approaches provide rich contextual insights, they do not generate highly precise quantitative measurements of movement trajectories, spatial coordinates, or dancer interactions. Future studies may therefore integrate ethnographic methods with motion-capture technologies, drone-based spatial mapping, computational geometry, geographic information systems (GIS), or kinematic analysis to generate more detailed representations of choreographic structures.

Second, the present study focuses specifically on the *Tumbu Tanah* Dance as practiced within particular Arfak communities in West Papua. Variations in choreography, ceremonial context, clan participation, and local interpretations may exist across different communities and regions. Comparative studies involving multiple Indigenous dance traditions across Papua and other regions of Indonesia may provide broader insights into how mathematical ideas emerge through diverse cultural performances.

Third, while the study identifies numerous mathematical structures embedded within the dance, it does not directly investigate how ethnomathematical learning experiences based on the *Tumbu Tanah* Dance influence students' mathematical achievement, spatial reasoning, cultural identity, or engagement in formal educational settings. Future research could therefore examine the pedagogical effectiveness of ethnomathematics-based instructional designs derived from Indigenous performance traditions.

Finally, the *Tumbu Tanah* Dance represents far more than a traditional cultural performance. It constitutes a sophisticated Indigenous spatial–numerical knowledge system through which the Arfak people express geometric reasoning, rhythmic organization, collective identity, ecological relationships, and ancestral continuity. The dance illustrates how mathematical knowledge may be embodied in movement, embedded within culture, and transmitted through communal practice across generations. By revealing the mathematical dimensions of this Indigenous performance tradition, the study contributes to the advancement of ethnomathematical scholarship, supports culturally responsive and decolonizing approaches to mathematics education, and highlights the importance of preserving Indigenous knowledge systems as valuable intellectual resources for contemporary society.

Conclusion

This study examined the ethnomathematical ideas embedded in the *Tumbu Tanah* Dance of the Arfak people in West Papua. The findings indicate that mathematical ideas are expressed through spatial organization, rhythmic coordination, movement patterns, and social participation. In particular, the *jey/srem* (linear), *ikrop* (semicircular), and *nimot* (circular) formations revealed geometric ideas related to lines, arcs, symmetry, rotation, and spatial organization. The rhythmic patterns demonstrated periodicity, repetition, and collective synchronization, while the organization of dancers according to kinship and ceremonial roles reflected practices related to grouping, classification, and numerical organization. These findings suggest that mathematical ideas are embedded in the cultural practices of the Arfak

community and are transmitted through embodied participation and intergenerational cultural practices rather than primarily through formal mathematical notation.

The study contributes to ethnomathematics by documenting a dynamic and embodied form of mathematical knowledge within an Indigenous cultural tradition that has received limited attention in mathematics education research. The findings also support the view that mathematical reasoning can emerge through bodily movement, spatial experience, rhythm, and social interaction. Methodologically, the combination of ethnographic observation, interviews, audiovisual documentation, spatial analysis, and mathematical interpretation provides an approach that may be adapted to the study of other Indigenous dances and embodied cultural practices.

The findings have implications for mathematics education, particularly in developing culturally responsive learning contexts. The formations and movement patterns identified in *Tumbu Tanah* may provide meaningful contexts for exploring geometry, symmetry, transformation, measurement, patterns, and spatial reasoning. Integrating such cultural practices into mathematics learning may also help students connect mathematical ideas with local knowledge and cultural experiences. However, such integration should be undertaken collaboratively and respectfully, with attention to the cultural meanings and community perspectives associated with the practice.

This study has several limitations. It focused on a single Indigenous cultural tradition and involved a relatively small group of cultural knowledge holders and experienced performers. Therefore, the findings are contextual and should not be generalized to other Indigenous communities without further investigation. In addition, the mathematical interpretations represent an analytical perspective developed from the collected data and may not encompass all possible Indigenous understandings of the dance. Future research could examine other Indigenous performance traditions in Papua and eastern Indonesia, investigate how mathematical knowledge is transmitted across generations, and explore the use of *Tumbu Tanah* in mathematics learning through participatory or design-based studies. Digital technologies, including motion capture and 3D modelling, may also provide further opportunities to document and visualize the spatial and rhythmic patterns of Indigenous cultural practices.

Finally, the *Tumbu Tanah* Dance provides an important example of how mathematical ideas can be expressed through movement, rhythm, spatial organization, and collective cultural practice. Recognizing such practices can broaden the scope of ethnomathematics and support mathematics education that values local knowledge, cultural diversity, and meaningful connections between mathematics and students' cultural environments.

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Conflicts of Interest

The authors declare no conflict of interest related to the research, authorship, and publication of this article.

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