Integrated Science Education Journal
Vol. 7, No. 2, March 2026, pp. 370~379
ISSN: 2716-3725, DOI: 10.37251/isej.v7i2.2665

Research Article

Ethnophysics of Tua Reta Lou Dance: Mapping Equilibrium, Torque, and Circular Motion for Contextual Physics Learning

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Article Info

Article history:

Received Jan 14, 2026
Revised Feb 03, 2026
Accepted Mar 11, 2026
OnlineFirst Mar 27, 2026

Keywords:

Ethnophysics
Local Wisdom
Mechanics Learning
Motion Dynamics
Traditional Dance

ABSTRACT

Purpose of the study: This study explores and identifies physics concepts embedded in the Tua Reta Lou dance as a form of local wisdom from Sikka Regency, East Nusa Tenggara, Indonesia, with a focus on motion-dynamics constructs that can be used as contextual resources for physics learning.

Methodology: This study employed a qualitative exploratory (ethnophysics) design. Data were collected through (i) field observations of Tua Reta Lou performances, (ii) photo/video documentation of key movement components and dancer bamboo interactions, and (iii) semi-structured interviews with dancers and cultural practitioners selected using purposive sampling (information-rich participants). Data were analyzed iteratively through qualitative reduction–display–conclusion procedures and analytical mapping of observed phenomena to mechanics constructs.

Main Findings: The Tua Reta Lou dance embodies key mechanics concepts, including rigid-body equilibrium and center of mass (balancing on the bamboo tip), torque and rotational equilibrium (force regulation through hands/feet and supporting dancers), moment of inertia (stability strategy via limb extension), and circular motion represented through centripetal force and angular momentum. These concepts are consistently represented through recurrent movement components during the performance.

Novelty/Originality of this study: This study provides a structured ethnophysics mapping of Tua Reta Lou into explicit motion-dynamics constructs and outlines a curriculum-aligned pathway to transform local cultural practice into contextual physics learning resources.

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1. INTRODUCTION

Physics is a core domain in science education that supports scientific literacy and develops learners' logical and analytical reasoning. However, physics is often perceived as difficult because classroom instruction may overemphasize symbolic manipulation and formula recall rather than conceptual meaning-making and interpretation of real-world phenomena. This difficulty is especially pronounced in mechanics, where students must connect abstract representations to observable motion [1]-[9].

Such difficulties are frequently linked to limited contextualization. When mechanics concepts are taught using examples that are detached from students' sociocultural environments, students may struggle to connect formal representations (e.g., free-body diagrams and torque equations) with observable experience, which can reduce engagement and constrain conceptual understanding. As a result, learners may memorize equations without being able to explain the underlying physical mechanisms [10], [11].

An ethnophysics perspective offers a principled pathway to contextualization by treating cultural practices as legitimate sites where physics principles are enacted implicitly. In this approach, local cultural activities can function as 'natural laboratories' in which equilibrium, rotation, and coordinated forces become observable and discussable, supporting students' sensemaking and bridging everyday experience with formal physics. Ethnophysics thus positions local wisdom not as an add-on, but as a meaningful context for developing scientific concepts [12]-[22].

Sikka Regency (East Nusa Tenggara, Indonesia) is rich in local wisdom, including traditional dances that involve complex embodied movements [23], [24]. One prominent example is the Tua Reta Lou dance, which features extreme balancing on bamboo and coordinated circular movements and is performed within the broader cultural expression of the Sikka community [25], [26]. Although prior ethnophysics studies have examined several Indonesian cultural practices, systematic documentation of motion-dynamics constructs in Tua Reta Lou remains limited, and existing work rarely translates such mappings into curriculum-relevant learning resources for secondary physics [27]-[30]. Consequently, teachers and researchers lack an explicit, concept-to-representation mapping that can be directly used in mechanics instruction and aligned with contemporary goals such as cultural preservation, 21st-century skills, and meaningful science learning [31]-[37].

Therefore, this study aims to (1) identify motion-dynamics concepts embedded in the core movement components of the Tua Reta Lou dance and (2) articulate how these concepts can be positioned as contextual resources for physics learning. The novelty of this study lies in providing a structured mapping from movement components to formal mechanics constructs and outlining instructional implications grounded in local wisdom. The research questions are: (RQ1) What motion-dynamics concepts are embedded in the core movement components of the Tua Reta Lou dance? (RQ2) How can these concepts be translated into curriculum-aligned resources for teaching mechanics in secondary physics? In doing so, the study clarifies a feasible pathway for culturally responsive mechanics learning.

2. RESEARCH METHOD

Research design: This study employed a qualitative approach with an exploratory research design to interpret physics concepts implicitly enacted in the Tua Reta Lou dance. A qualitative approach was chosen because the study aims to explore and understand cultural phenomena in depth and then interpret them into relevant physics concepts [38], [39].

Setting: The research was conducted in Sikka Regency, East Nusa Tenggara Province, Indonesia, focusing on the cultural practice of the Tua Reta Lou dance. Figure 1 summarizes the overall research flow.

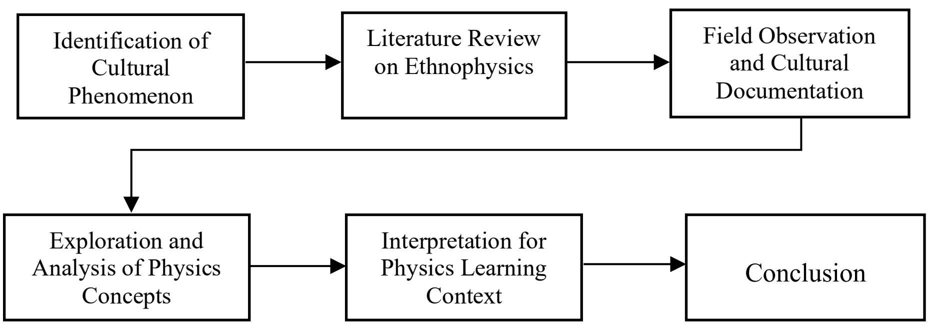

Figure 1. Research Flow

The research subjects were not determined in the form of individuals quantitatively, but rather in the form of cultural activities that were observed and the cultural actors involved in them. The research informants consisted of Tua Reta Lou dancers who were selected purposively based on their direct involvement, experience, and understanding of the cultural practices being studied [39]. Data collection was carried out using three main techniques, namely observation, interviews, and documentation. Observations were made directly during performances of the Tua Reta Lou dance to capture movement patterns, dancers' body positions, interactions among dancers, and the use of bamboo props. Interviews were conducted with purposively selected informants to clarify movement meaning and performance context. Documentation (photos/videos) was used to support movement analysis and reporting, consistent with multimodal approaches to capturing and interpreting performance phenomena [40]-[42]

Instruments and measurement (operationalization): This study used an observation guide and a semi-structured interview protocol. The unit of analysis was a recurring movement component; each component was described through observable physical phenomena (posture, contact points, force directions, rotation tendency, and movement trajectory) and then mapped to a formal mechanics construct (e.g., equilibrium, center of mass, torque, moment of inertia, circular motion), drawing on interpretive approaches to lived movement experience in performance contexts [43].

Data were analyzed through data reduction, data display, and conclusion drawing. In the data reduction stage, data from observations, interviews, and documentation were selected and focused on information relevant to motion-dynamics concepts. The data display stage compiled findings systematically in a thematic narrative and a mapping matrix linking cultural phenomena with physics concepts. This analysis follows the Miles and Huberman framework commonly used in educational and cultural research [44]. Analytical mapping included free-body diagrams and equation-based interpretations (Eqs. 1-18) as explanatory outputs grounded in classical mechanics sources [45]-[50]. Because the study is qualitative and does not test SEM-based hypotheses, SmartPLS/AMOS were not used.

Data validity was maintained through source and technique triangulation by comparing the results of observations, interviews, and documentation. Triangulation increases confidence in qualitative findings and minimizes researcher subjectivity in interpretation [51]. Ethical considerations: Prior to interviews and documentation, participants were informed about the study purpose, and participation was voluntary. Consent was obtained for recording interviews and capturing photos/videos for documentation.

3. RESULTS AND DISCUSSION

The results address by showing that each core movement component in the Tua Reta Lou dance embodies distinct yet interrelated motion-dynamics constructs. Table 1 summarizes the mapping between movement components, observable physical phenomena, and the corresponding mechanics concepts that can be leveraged as contextual resources for physics learning.

Table 1. Physical Concepts in the Movements of the Tua Reta Lou Dancers

Movement Component	Description	Physics Concept	Equation
Dancer on bamboo	Body lying horizontally with center of mass above the fulcrum	Static equilibrium, center of mass	$\Sigma F_y = 0, \Sigma\tau = 0$ … (1)
The dancer supports the bamboo	Providing normal force and friction force to stabilize the bamboo	Newton's Third Law (action-reaction), normal force	$F_{action} = -F_{reaction}$ … (2) $f = \mu N$ …(3)
Shifting the dancer's body	Dancers shift their body position to maintain balance	Torque, center of mass	$\tau = F \cdot sin\theta$ … (4) $I = F \cdot \Delta t$ … (5)
Arms/legs are extended	Dancers expand their mass distribution to maintain stability	Moment of inertia, mass distribution	$I = \Sigma mr^2$ … (6) $\alpha = \frac{\tau}{I}$ … (7)
The dancer circles	Circular motion with centripetal force	Circular motion, centripetal force	$Fs = \frac{mv^2}{r}$ … (8)

The Concepts of Balance and Center of Mass in the Tua Reta Lou Dance

Field observations show that one of the main characteristics of the Tua Reta Lou dance is the position of the male dancers lying on the tip of a bamboo pole as their only point of support. This body position requires a high degree of balance because the dancer's entire body weight is concentrated on a single point of contact. Physically, this condition shows that the requirements for rigid body equilibrium are met, namely that the resultant force and the resultant moment of force are equal to zero [52].

The dancer's body position to maintain stability can be clearly observed in Figure 2. The figure shows that the dancer places her stomach directly above the tip of the bamboo so that her center of mass is above the fulcrum. When the body tends to tilt, the dancer reflexively adjusts the position of her hands and feet to restore balance. This phenomenon shows that the concept of center of mass is not only theoretical, but also present in cultural practices and can be surfaced as a contextual learning resource [15], [35].

Figure 2. The Position of the Male Dancer in the Tua Reta Lou Dance, Balancing on the Tip of a Bamboo Pole as the Main Point of Support.

This image shows the equilibrium condition of a rigid body, where the dancer's center of mass must be directly above the fulcrum for the system to remain stable. Physically, equilibrium is achieved when the resultant force and the resultant moment of force are equal to zero, as explained in classical mechanics [45], [46]. Dancers intuitively adjust their body position so that their center of mass remains above the bamboo fulcrum. This phenomenon is in line with the concept of center of mass, which states that the stability of an object is largely determined by the position of its center of mass relative to the support surface [47]. This finding shows that the principle of center of mass, which is often understood mathematically in the classroom, has actually long been practiced intuitively in local culture.

Moment of Inertia and Rotational Stability of the Dancer’s Body

In addition to the center of mass, the stability of the dancer's body is also influenced by the moment of inertia. Observations show that dancers tend to stretch their arms and legs when in extreme positions on the bamboo. This action is not merely for the aesthetics of the dance, but an intuitive strategy to maintain body balance based on rotational dynamics principles [45]-[48].

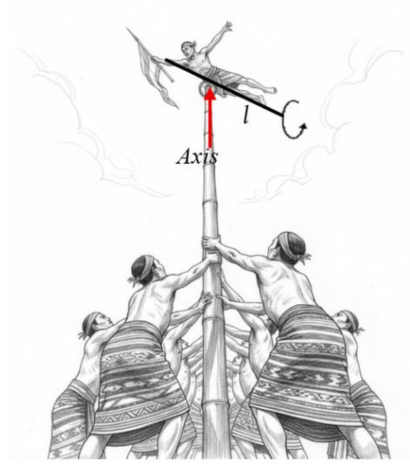

Figure 3. The position of the Tua Reta Lou dancer with arms and legs extended while on the bamboo.

An interview with the dancer lying on the bamboo revealed that her main action to maintain balance was to focus her entire weight on her abdominal area. According to her, the sensation she felt was like creating a “straight line” connecting her stomach directly to the bamboo's fulcrum. She added that to counteract small swaying movements or gusts of wind, she spread her arms and legs as wide as possible.

The body position with arms and legs extended as shown in Figure 3 increases the mass distribution relative to the axis of rotation at the bamboo fulcrum. Physically, this condition increases the moment of inertia, making the dancer's body more resistant to small rotational disturbances. In this condition, the dancer’s moment of inertia relative to the axis is determined by the length of the body, which represents the l, and the body mass, which represents the [46], [48]-[50]. Mathematically, this follows the equation:

$$I = \frac{1}{12} m l^2 \ldots (9)$$

These theoretical calculations show that the longer the dancer's mass distribution (arms and legs extended), the greater the moment of inertia, making the dancer more stable against small rotational changes on the bamboo. The dancer's subjective experience of feeling more 'solid' in this position reinforces the analysis that increased moment of inertia plays an important role in rotational stability [53], [54]. The dancer's action of focusing weight on the abdomen and feeling a "straight line" to the fulcrum is an intuitive application of the concept of center of mass. In physics theory, a rigid object will be stable if its center of mass is directly above the support surface so that the gravitational force through that point does not produce a moment that causes rotation [45]. Biomechanical research by Winter [53] emphasizes that control of the center of mass is a key requirement in maintaining human balance, both in static and dynamic movements. Studies on balance in gymnasts [54] also show that the more precisely the center of mass is positioned relative to the support surface, the higher the level of stability a person has when in an extreme position. This explains why dancers instinctively try to "align" their bodies with the point of contact with the bamboo.

From a physics perspective, this action increases the distribution of mass around the axis of rotation, thereby increasing the moment of inertia, which ultimately makes the system more resistant to small rotational disturbances [48]. This finding is in line with various ethnophysical studies of traditional dance, which show that body movements in dance often reflect the principles of rotational dynamics, even though the performers are not aware of this [27]. Thus, the Tua Reta Lou dance can be viewed as a contextual representation of the concept of moment of inertia that is relevant to physics education.

Torsion Analysis in the Interaction between Dancers and Bamboo

Analysis of the labeled image shows that there are several torques acting on the bamboo and dancer system. The first is the torque due to the gravitational force of the male dancer's body above the bamboo. This force acts downward with a magnitude *of*

$$F_g = m \cdot g \quad \dots (9)$$

where m is the mass of the dancer and g is the acceleration due to gravity. The resulting torque depends on the distance of the line of action of the force from the axis of the bamboo, labeled as r_g. Thus, the gravitational torque can be written as

$$\tau_g = r_g \cdot F_g \quad \dots (10)$$

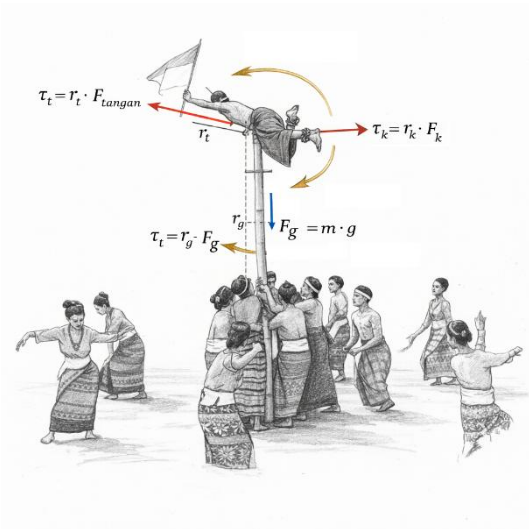

Figure 4. Torque Analysis of the Dancer's Movement

Second is the torque caused by the dancer's hand pressing against the side of the bamboo. This force helps balance the moment caused by gravitational force. If the distance of the hand from the axis of the bamboo is r_t , then the torque can be written as

$$\tau_t = r_t \cdot F_{hand} \quad \dots (11)$$

Similarly, the dancer's foot also exerts a pressing force with a distance *of* r_k , resulting in

$$\tau_k = r_k \cdot F_{foot} \quad \dots (12)$$

It is the combination of the torque from the hands and feet that allows the dancer to maintain balance even in dangerous positions. This theory is in line with the principle explained by Young & Freedman [46], that rotational equilibrium is achieved when the sum of the moments of all forces acting together is zero.

The results of this study show that the hands and feet of dancers function as generators of pressure forces that provide positive or negative moments, depending on the direction of pressure. This is consistent with the research by Mangoensong & Yanuartuti [24], which states that the distribution of muscle forces in traditional dance has biomechanical implications for maintaining stability. Similarly, the results of a study by Putri et al., [37] on Saman dance show that the coordination of the muscles in the hands and feet produces effective compressive forces in creating harmony of movement.

At the bottom, another dancer provides a balancing force on the bamboo to keep it stable. This balancing torque is very important because it counteracts the resultant torque from above. The equation is

$$\tau_p = r_p \cdot F_p \qquad \dots (13)$$

where r_p is the distance of the balancing force from the axis of the bamboo. If equilibrium is achieved, then the following law applies:

$$\tau_{gravity} + \tau_{hand} + \tau_{foot} = \tau_{balancing\ force} \quad \dots (14)$$

The dancers holding the bamboo explain that their role is to support the bamboo so that it remains upright and does not shift. They focus the strength of their hands and feet to hold the bamboo steady and prevent any unwanted movement. They also state that coordination and teamwork are very important, as they are the foundation for the dancers above, who are carrying out an important mission. Each member must feel and respond to the bamboo's movements simultaneously to maintain stability. They call this a “shared feeling” that the entire team must have.

This principle is consistent with the theory of rotational equilibrium in rigid body mechanics [49]. Research on force distribution in circus acrobatic teams Paoletti et al., [52] shows the importance of team coordination in maintaining human structural balance. Similarly, supporting dancers must be synchronized so that the forces applied are uniform and do not cause excessive moments that could cause the bamboo to shift. These findings show that the balance of bamboo in the Tua Reta Lou dance is not accidental, but rather the result of complex interactions between the forces exerted by the dancers' bodies. In other words, the dancers intuitively understand how to regulate force and momentum to keep the system stable. This reinforces the view that traditional culture is an authentic means of learning science.

The implication of this analysis for learning is that physics teachers can use the Tua Reta Lou dance as a concrete example to explain the concept of torque. Students can be asked to draw diagrams of the forces and moments on the dancers, calculate the magnitude of the torque using estimated body mass and arm moment distance data, and discuss how equilibrium can be achieved. In this way, previously abstract learning can become more meaningful.

Motion Dynamics Analysis

In addition to torque, the Tua Reta Lou dance also features dynamic movement. Dancers moving in a circle under the bamboo experience centripetal force. Observations show that these movements are performed at a steady rhythm, in sync with the sound of the Gong Waning [25], [26]. This is in line with the centripetal force equation [46], [48], [50].

$$F_c = \frac{mv^2}{r} \qquad \dots (15)$$

which states that the faster the dancers move, the greater the centripetal force required to maintain a circular trajectory.

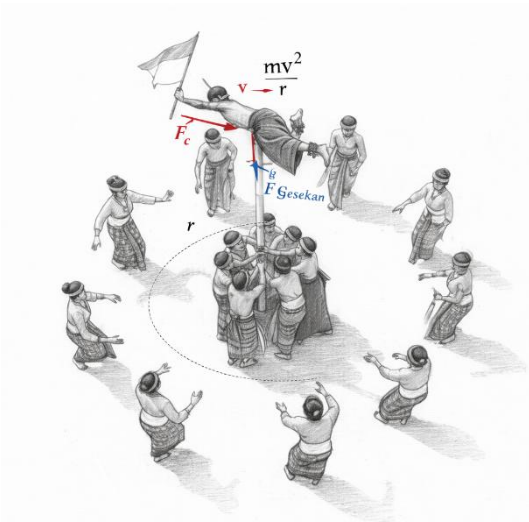

Figure 5. Female Dancers Dancing Around Bamboo

The female dancers dancing around the bamboo explain that their movements form a circle that continuously moves to the rhythm of the music. They state that the meaning of this dance is to spy on the enemy. Their dance is not only spiritual support, but also a form of physical and tactical support. By moving around the bamboo, they provide moral support and energy to the dancers above, who act as spies. They also believe that their movements help obscure the enemy's view, and at the same time, provide 'guidance' for the dancers above to move and spy safely. Such meaning-making and embodiment are consistent with cultural and interpretive perspectives in dance studies [24]. This movement can also be linked to angular momentum. Dancers moving in a circle have angular momentum

$$L = mvr \quad \ldots (16)$$

the value of which depends on mass, velocity, and radius of the trajectory. Thus, this dance naturally demonstrates how angular momentum works in everyday life. If the dancers accelerate their steps, the angular momentum will increase, and its effect on the stability of the bamboo will change.

The circular movements of the female dancers are performed with a relatively uniform tempo, allowing the motion to be represented through angular velocity and centripetal requirements. This provides a culturally grounded entry point for discussing uniform circular motion without assuming formal prior knowledge.

$$E_p = mgh \quad \ldots (17)$$

where hh is the height of the dancer's position. Meanwhile, dancers moving in a circle have kinetic energy equal to

$$Ek = \frac{1}{2}mv^2 \qquad (18)$$

Both energies contribute to the overall dynamics of the dance, so their combination can be analyzed as an application of the law of conservation of mechanical energy.

In addition to mechanical energy, Newton's laws are also clearly evident. The interaction between the dancer's feet and the floor, as well as the dancer's hands on the bamboo, are examples of the application of Newton's third law. Every action performed by the dancer produces an equal and opposite reaction, so that the system remains balanced. This is what allows the dance to proceed harmoniously without causing the bamboo to fall [47], [48], [50]. This theory is explained in detail by Halliday, Resnick, & Walker [47], who emphasize the relationship between potential and kinetic energy in the dynamics of motion. This study found that dancers intuitively balance the use of mechanical energy to maintain the rhythm of the dance. This phenomenon is consistent with the research by Wardah et al., [28] on the Lahbako dance, which emphasizes energy efficiency in traditional dance movements. The harmony between the potential energy of the dancers on the bamboo and the kinetic energy of the dancers moving in a circle demonstrates a complex physical synergy in maintaining the harmony of the dance.

These results confirm that the Tua Reta Lou dance is rich in physics concepts that can be integrated into learning. Teachers can use the dancers' circular movements to teach the concepts of centripetal force, angular momentum, and energy [31]-[33]. Through an ethnophysics approach, students not only understand the equations, but are also able to see their application in their own culture, supporting meaningful and culturally relevant science learning [17], [21], [35].

Embedded motion-dynamics concepts: The findings indicate that Tua Reta Lou consistently instantiates mechanics constructs such as rigid-body equilibrium, center-of-mass control, torque regulation, moment of inertia as a stability strategy, and uniform circular motion. This supports the ethnophysics view that physics principles can be enacted implicitly in cultural practices and surfaced through systematic observation and analytical mapping [17], [20], [22]. Mechanistic interpretation: The bamboo-balancing segment imposes a narrow base-of-support constraint; therefore, stability requires continuous alignment of the center of mass above the support point and active regulation of counter-torques through limb placement. Limb extension plausibly increases rotational inertia, reducing sensitivity to small perturbation torques, consistent with standard rigid-body mechanics perspectives [45], [46], [49], [50]. This interpretation is also consistent with human balance and coordination research in biomechanics and balancing tasks [52]-[54].

Integration with prior studies: These results align with ethnophysics literature showing that local cultural activities can function as contextual anchors for physics sensemaking [15], [17]. They are also consistent with embodied-learning perspectives in which movement-based representations (e.g., dance) can support engagement and concept formation in STEM [23]. Related work has mapped mechanics and rotational dynamics concepts in other traditional dances and local wisdom contexts [16], [27], [29]. Broader perspectives on culturally responsive and indigenous-informed science education further support using community cultural resources as legitimate learning contexts [18], [35]. The present study extends this line of work by providing a concept-to-equation mapping specific to Tua Reta Lou, which has been under-documented in prior ethnophysics research.

The mapping in Table 1 enables teachers to design learning activities that progress from observation to representation. For example, students can (i) segment a movement component, (ii) sketch a free-body diagram and identify moment arms, and (iii) connect qualitative observations to equilibrium and rotational dynamics relations (Eqs. 1-14). For circular motion, students can describe trajectories and infer centripetal requirements (Eqs. 15-16). Such tasks may support culturally responsive instruction by grounding mechanics in familiar local contexts and strengthening students' representational competence [3], [8], [11], [35].

Practical implications for curriculum and assessment: The findings can inform the development of short ethnophysics modules (e.g., worksheets or multimedia clips) aligned with secondary mechanics topics, including technology-supported learning resources [21], [32]. Assessment can emphasize explanation quality and representational competence (diagram accuracy, identification of forces/torques, and coherence of reasoning), which aligns with broader aims of developing critical thinking and 21st-century skills in science learning [1], [2], [31], [34]. Novelty and contribution the key contribution of this study is a structured ethnophysics mapping of Tua Reta Lou into explicit motion-dynamics constructs and formal representations that can directly inform material development. This clarifies how local wisdom can be operationalized as an evidence-based contextual resource in physics learning and complements recent ethnoscience/ethnophysics syntheses and technology-integration approaches [17], [21], [22].

Limitations this study is interpretive and context-specific, focusing on observed performances and informant narratives in one cultural setting. The study does not test learning outcomes (e.g., pre-post gains); such evaluation would require an additional classroom intervention study, as conducted in some ethnophysics work using quantitative models. Therefore, conclusions are limited to concept identification and instructional potential within the analyzed context. Future studies should (i) develop and validate ethnophysics-based teaching materials derived from this mapping, (ii) evaluate classroom implementation using mixed methods (conceptual understanding, engagement, and representational competence), and (iii) compare mechanics mappings across multiple traditional dances to examine transferability and boundary conditions. Future work can also leverage more systematic multimodal documentation and analysis approaches in performance research, examine learners' and performers' experiential dimensions such as flow during coordinated group performance and align with emerging trends in physics education research.

4. CONCLUSION

This study identified core motion-dynamics concepts embedded in the Tua Reta Lou dance, including rigid-body equilibrium and center-of-mass control (balancing on bamboo), torque regulation and rotational equilibrium (hand/foot and team-support forces), moment of inertia as a stability strategy (limb extension), and circular motion represented through centripetal requirements and angular momentum. These findings contribute to the ethnophysics literature by providing a structured mapping from culturally meaningful movement components to formal mechanics constructs and representations. Practically, the mapping offers a curriculum-aligned foundation for developing contextual mechanics learning materials and culturally responsive instruction. Future research should transform this mapping into validated teaching modules and evaluate their impact in classroom settings.

ACKNOWLEDGEMENTS

The author would like to thank the LPPM of Widya Mandira Catholic University for funding this research.

AUTHOR CONTRIBUTIONS

ED, CMMM, OAK, MYK and MLFF jointly designed the research, collected and analyzed data through an exploratory ethnophysical approach to the Tua Reta Lou dance, and compiled and edited the article manuscript to its final version.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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