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Menelusuri Etnofisika dalam Gamelan Jawa: Menjembatani Warisan Budaya dan Pembelajaran Fisika Berbasis STEAM

(Exploring Ethnophysics in Javanese Gamelan: Bridging Cultural Heritage and STEAM-Based Physics Learning)

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ABSTRACT. This study aims to explore the ethnophysics characteristics of Javanese gamelan and to analyze how these characteristics can be integrated into STEAM-based physics learning. Specifically, the research seeks to identify the ethnophysics phenomena embedded in gamelan instruments, examine their cultural meanings, and formulate pedagogical implications for culturally responsive science education. Using a qualitative ethnographic design, data were collected through interviews, observations, and documentation involving gamelan craftsmen, pengrawit, and cultural experts. The findings show that instruments such as *saron, demung, peking, kenong, gong,* and *kendang* embody fundamental physics principles, including vibration, resonance, frequency, amplitude, and damping, which arise naturally from their material composition, construction processes, and performance techniques. At the same time, these instruments carry symbolic values rooted in Javanese philosophy, representing harmony, balance, collectivism, and spiritual interconnectedness. The combination of scientific and cultural dimensions demonstrates that gamelan can serve as an authentic learning medium that bridges traditional knowledge with physics concepts taught in modern learning frameworks. Pedagogically, integrating ethnophysics into STEAM supports interdisciplinary learning that blends scientific investigation, engineering design, mathematical reasoning, technological tools, and artistic expression. This approach enhances contextual understanding, creativity, inclusivity, and cultural identity. The study proposes the Ethno-STEAM model as an innovative framework for decolonizing science education by positioning cultural heritage as a legitimate source of scientific insight. Overall, the ethnophysics of Javanese gamelan offers a transformative pathway for physics learning that is both scientifically rigorous and culturally grounded.

INTRODUCTION

In recent years, the integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) has been increasingly recognized as a transformative educational paradigm that connects scientific inquiry with creativity, culture, and sustainability [1]. STEAM frameworks have been designed to unite analytical reasoning with artistic expression, enabling learners to construct meaning through both scientific and aesthetic perspectives [2]. The inclusion of the arts has broadened the traditional STEM model by fostering imagination, empathy, and innovative problem-solving that are essential for future learning environments [3].

Within this evolving vision of education, cultural heritage plays a vital role in bridging traditional wisdom with future-oriented scientific literacy. Ethical enactivism in STEAM positions culture, creativity, and sustainability at the heart of educational transformation [4]. The STEAM+X model extends STEAM into transdisciplinary dimensions by integrating culture, architecture, and history as active components of scientific inquiry [5]. From this perspective, bridging cultural heritage and science learning enables students to perceive knowledge as a continuum that spans from inherited tradition to modern innovation.

In Indonesia, this idea is embodied in the concept of ethnoscience, specifically ethnophysics, which reconstructs indigenous knowledge into formal scientific frameworks [6]. Ethnophysics bridges empirical observation in traditional practices with physics ideas implemented in current learning practices, demonstrating that local technologies and arts contain implicit understandings of natural phenomena [7]. Such an approach aligns with the Merdeka Curriculum's orientation toward contextual and culturally grounded learning, which emphasizes the transmission of heritage-based knowledge as part of future-ready education [8]. By integrating scientific concepts with cultural identity, ethnophysics transforms science learning into an inclusive and reflective process that connects generations [9].

Traditional arts, such as karawitan and Javanese gamelan, represent more than just aesthetic practices. They function as moral and philosophical systems that embody balance, harmony, and cooperation [10]. Exploring ethnophysics within such cultural heritage creates an opportunity to bridge physics with lived cultural values, cultivating students' sense of identity and belonging while nurturing creativity and scientific literacy for the future.

The Javanese gamelan ensemble exemplifies how cultural heritage can bridge artistic expression and scientific understanding. Each instrument, crafted from bronze, wood, and other materials, operates through vibration and resonance, illustrating the fundamental principles of sound, wave motion, and frequency [11]. The *saron*, as the core melodic instrument, demonstrates the relationship between the bar's length, thickness, and material density with its tonal frequency and amplitude, thus providing a tangible entry point for physics learning [12].

From a mathematical perspective, the geometric proportions and tuning systems of gamelan offer opportunities to integrate measurement, pattern, and symmetry into STEAM-based exploration [13]. In physics, these aspects are closely related to one of the fundamental introductory topics, *Measurement and Estimation*, which includes discussions of units, standards, and the International System of Units (SI) as the foundation for understanding quantitative relationships in physics phenomena. The spatial arrangement of wilahan or keys reflects geometric harmony and transformation principles that parallel mathematical reasoning [14]. These relationships reflect embodied STEAM learning, in which art and science merge through sensory, performative, and creative experiences [15].

Beyond its physical dimensions, gamelan embodies the cosmological and ethical philosophy of Javanese culture. Every instrument contributes to an ensemble that symbolizes interdependence and collective harmony [10]. This concept mirrors the collaborative spirit of STEAM education, which values interdisciplinary synthesis and teamwork. Through an ethnophysics inquiry, gamelan becomes not only a symbol of cultural heritage but also a bridge to meaningful, humanistic, future-oriented science learning.

In recent ethnophysics research across Indonesia, traditional arts such as Reog Ponorogo have been utilized to contextualize motion and energy concepts in physics learning, resulting in increased engagement and conceptual understanding [7]. Indigenous craft traditions such as brick making and metal forging can be reconstructed as models of pressure, heat, and energy transfer [6]. These studies reveal how cultural practices can bridge historical wisdom and scientific literacy. Integrating gamelan into STEAM-based physics learning offers a pathway for bridging tangible cultural artifacts with abstract scientific concepts, aligning with the essence of cross-disciplinary education in Asia [16]. In South Korea, STEAM implementation succeeded when programs connected students' creativity and cultural engagement with disciplinary integration [17]. Thus, integrating gamelan into physics education reflects an educational movement already evident across Asia, where cultural identity and scientific literacy converge.

Despite the global expansion of STEAM education, many models remain anchored in Western epistemologies that prioritize laboratory experimentation over cultural contextualization [1]. In contrast, emerging Indonesian research demonstrates a shift toward integrating local wisdom into science learning through ethnoscience and ethnophysics approaches [9]. However, the systematic integration of cultural heritage, especially Javanese gamelan, into STEAM-based physics learning remains limited [13].

Previous studies on gamelan have primarily focused on its musical and artistic dimensions, while its potential as an ethnophysics and pedagogical resource remains underexplored [14]. Although locally based initiatives, such as the integration of Reog Ponorogo, have proven effective in enhancing student motivation and conceptual learning [7], comprehensive frameworks that bridge traditional arts and physics education have yet to be established. Effective STEAM design should not only build cognitive competence but also sustain cultural identity and creativity [18].

Challenges in the Indonesian educational context include a lack of localized teaching resources, limited teacher capacity, and insufficient alignment between policy and classroom implementation [6] [8]. Addressing these challenges requires educational models that actively bridge scientific reasoning with cultural heritage. Decolonizing STEAM means creating learning systems that value local epistemologies as integral to future scientific innovation [4]. Within this framework, the ethnophysics study of Javanese gamelan becomes a vital effort to connect cultural continuity with the development of STEAM-based physics education.

Building on the conceptual and contextual foundations discussed above, this study aimed to explore the ethnophysics characteristics of Javanese gamelan and examine how these characteristics can be meaningfully integrated into STEAM-oriented physics education. Specifically, the research sought to (1) identify and describe the physics phenomena embedded in the construction and performance practices of Javanese gamelan instruments; (2) analyze the relationships between these physics phenomena and the cultural meanings that underpin gamelan as a form of indigenous knowledge; and (3) discuss the pedagogical implications for designing culturally responsive, STEAM-based physics learning models that foster creativity, inclusivity, and contextual understanding.

By situating the exploration of physics within the lived cultural expressions of Javanese gamelan, this study contributes to the broader discourse on decolonizing science education and advancing culturally grounded STEAM pedagogies. It provides a framework illustrating how traditional arts can function not only as cultural heritage but also as epistemological resources that bridge scientific reasoning and local wisdom. Ultimately, the research highlights the potential of ethnophysics as a transformative pathway for developing physics learning that is both scientifically rigorous and deeply rooted in Indonesia’s cultural identity.

RESEARCH METHOD

This research employed a qualitative, ethnographic approach and was conducted over a period of June to October 2025 (5 months). The study explored the ethnophysics characteristics of Javanese gamelan and reconstructed its physics and cultural aspects into scientific knowledge for STEAM-based physics learning. The subjects consisted of five Javanese gamelan practitioners, including three *pengrawit* (gamelan players), one *empu gamelan* (gamelan craftsman), and one cultural expert in *karawitan* (traditional Javanese musical art based on gamelan).

Data were collected through in-depth interviews, observation, and documentation. Data were analyzed descriptively using the Miles and Huberman model (data collection, data reduction, data display, and data verification). The data analysis process was conducted continuously throughout the study. The obtained data were then verified and reconstructed into scientific concepts. Data interpretation was carried out through discussions with experts in ethnophysics and physics education. The validity of the data was ensured through a credibility test using triangulation, comparing the results of observations, interviews, and documentation for the same research objects.

Data on the history and process of gamelan making were collected from the empu of the gamelan and a cultural expert at the “Sri Rejeki” gamelan production workshop in Sukoharjo, Central Java. This data collection was conducted while the researcher accompanied the “Panca Manggala” art group, which was ordering a complete set of gamelan instruments to be delivered to Ternate. Subsequently, data on the techniques of playing gamelan were obtained from the pengrawit after the instruments had arrived at the “Panca Manggala” Art Studio in Ternate, North Maluku.

RESULTS AND DISCUSSION

Results

The research identified six types of Javanese gamelan instruments, ordered by the Panca Manggala art group: *saron, demung, peking, kenong, gong,* and *kendang*. Each instrument exhibited unique material characteristics, manufacturing techniques, and acoustic behaviors. All instruments were handcrafted by *empu gamelan* at the Sri Rejeki workshop in Sukoharjo, Central Java.

Saron (Pélog and Sléndro Tuning Systems)

(a) (b)

Figure 1. (a) *Rancakan*-Making Process and (b) *Saron*, also known as *Saron Barung*.

The *saron* consisted of nine metal bars of spring steel, manually forged to achieve the required dimensions and natural frequencies. Spring steel was chosen for its high elasticity and stable vibrational response. Each bar was mounted on two small supports made of dense EVA foam, which acted as vibration dampers to minimize unwanted energy loss. Small nails were inserted on both sides of the bars to prevent lateral displacement during oscillation.

The wooden frame (*rancakan*) was crafted from the core of mahogany wood, known for its dense fiber structure and high acoustic stability. The bar arrangement allowed free oscillation, while the hollow cavity beneath functioned as a natural sound resonator. The mallet was made of hardwood, medium in size, and played with one hand, while the other hand muted the bar to control resonance (muting technique).

Two tuning systems were applied in this study: the Pélog and Sléndro tuning systems. The Pélog system, with seven tones and unequal frequency intervals, produces a warm, expressive timbre. In contrast, the Sléndro system, comprising five tones with nearly equal frequency intervals, produces a more balanced, stable tonal quality. From a physics perspective, the distinction between these two systems manifests in variations in bar length and their corresponding natural frequencies, with differences in physical dimensions and material properties directly influencing the acoustic characteristics of each tuning system.

Demung (Pélog and Sléndro Tuning Systems)

Figure 2. *Demung*, also known as *Saron Panembung*.

The *demung* contained seven spring steel bars, larger and thicker than those of the *saron*, producing lower-pitched tones with longer resonances. Each bar rested on EVA foam supports with small nails on the sides for mechanical stability. The wooden frame was made from the core of mahogany wood, manually carved with traditional Javanese motifs that combined artistic beauty with structural precision.

The mallet was larger and heavier than that of the *saron*, with a rounded head to maintain a mellow tone despite its lower pitch. Compared to the *saron*, the *demung* exhibited lower frequency, greater amplitude, and slower damping, consistent with its higher mass and longer vibrating length. Both the pélog and sléndro tuning systems were adjusted through manual auditory tuning, relying entirely on the craftsman's ear and experience.

Peking (Pélog and Sléndro Tuning Systems)

Figure 3. *Peking*, also known as *Saron Penerus*.

The *peking* was the smallest instrument in the metallophone family, consisting of seven forged spring-steel bars. The bars were thinner and shorter than those of the *saron* and *demung*, producing higher frequencies with shorter resonance time. Each bar was placed on EVA foam supports with nail pins at both sides for stability during vibration.

The frame was also made of a mahogany core, serving as a compact resonator. The mallet was the smallest among the three instruments, designed for rapid and precise strikes. The *peking* produced bright, penetrating sounds, typically used for fast, interlocking rhythmic patterns (imbal).

When compared, the *peking* instrument produced the highest tones, the *Saron* generated medium pitches, and the *Demung* produced the lowest tones. These relationships clearly demonstrate the physics correlation between bar length (L) and oscillation frequency (f), where shorter bars vibrate at higher frequencies and longer bars at lower frequencies, consistent with the theoretical model of a vibrating elastic beam that governs the acoustic behavior of gamelan instruments.

Kenong (Five Tones)

(a) (b)

Figure 4. (a) *Kenong*-Making Process and (b) *Kenong*.

The *kenong* consisted of five metal *gongs* shaped like inverted bowls, mounted on a mahogany frame made from the trunk's core. Each *kenong* was made from forged metal plates (iron–brass alloy) with a raised central boss that determined its resonant frequency. *Kenong* tones were of medium pitch and served as rhythmic and melodic markers in the gamelan ensemble. The mallet was made of hardwood wrapped with thick string, providing a soft striking surface that prevented harsh collisions. The carved wooden frame contained resonant cavities beneath each *kenong* to amplify sound projection.

Gong (Seven Tones)

Figure 5. A set of *gongs* with seven tones.

The *gong* set consisted of seven circular metal plates of varying diameters, made from an iron–brass alloy, and repeatedly forged to achieve the required curvature and central boss. Each *gong* was suspended from a mahogany frame (gayor), made from the tree’s central section to ensure mechanical strength and acoustic stability.

The mallet was made of hardwood wrapped in thick cloth, producing low-frequency tones with long resonance decay. The *gong* produced the lowest pitch and the longest resonance in the ensemble, symbolizing the end of a melodic cycle (*gongan*). From a physics viewpoint, the *gong* demonstrated two-dimensional standing waves and metallic resonance modes, often modeled in vibrational acoustics studies.

Kendang (Four Types: Ciblon, East Javanese, Bem, and Small)

(a) (b)

Figure 6. (a) *Kendang*-Making Process and (b) *Kendang Bem*

The *kendang* was constructed from solid jackfruit wood, lathe-machined and hollowed at the center to create a cylindrical resonator. Jackfruit wood was selected for its density, durability, and warm tonal quality. Both drumheads were covered with goat-skin membranes, stretched and tensioned using natural rope bindings. Goat skin provided high responsiveness and produced distinct tones, depending on the amount of hand pressure applied.

Four types of *kendang* were identified in the ensemble: *Ciblon*, which produced high-pitched and dynamic tones; the *East Javanese kendang*, which generated mid-range tones with firm rhythmic articulation; the *Bem kendang*, which produced low fundamental tones; and the *small kendang*, which served as an accent instrument in fast rhythmic patterns. Functioning as the rhythmic and dynamic controller of the ensemble, the *kendang* exemplified key physics principles such as membrane vibration, pressure wave propagation, and amplitude modulation, illustrating the interplay between mechanical oscillations and acoustic energy transmission in traditional percussion instruments.

Discussion

Identification and Description of Ethnophysics Phenomena Embedded in the Construction and Performance of Javanese Gamelan

This section presents findings related to the first research question, which aimed to identify and describe the physics phenomena embedded in the construction and performance practices of Javanese gamelan instruments. The findings revealed that each gamelan instrument exhibited distinct physics characteristics, determined by its material, shape, and function. In general, the observable physics phenomena were related to vibration, resonance, frequency, amplitude, and damping.

Instruments such as *saron*, *demung*, and *peking* belonged to the category of vibrating metal bars. When a bar was struck, the mechanical energy from the mallet caused the bar to undergo flexural vibration. The frequency of the produced sound depended on the length, thickness, and elastic modulus of the material. Longer bars generated lower pitches, while shorter bars produced higher ones. The supporting base made of EVA foam functioned as a partial vibration damper, allowing the bars to oscillate steadily without rapidly losing energy while maintaining tonal stability.

The fundamental frequency of vibrating metal bars in gamelan instruments such as the *saron*, *demung*, and *peking* can be theoretically explained using the Euler–Bernoulli beam vibration model. A metal bar with free–free boundary conditions vibrates in flexural modes governed by the beam's elastic and geometric parameters [19]. The behavior is described by the classical Euler–Bernoulli equation of motion:

$$EI\frac{\partial^4 y}{\partial x^4} = \rho A\frac{\partial^2 y}{\partial t^4} \quad (1)$$

Where E is Young's modulus, I is the area moment of inertia, ρ is the material density, and A is the cross-sectional area. Solving this differential equation with free–free boundary conditions yields a set of characteristic constants β_n, which define the mode shapes of the vibrating bar. For the fundamental mode, the characteristic value β_1 = 4.730 [20].

From this, the fundamental angular frequency is expressed as:

$$\omega_1 = {\beta_1}^2 \sqrt{\frac{EI}{\rho A L^4}}, \tag{2}$$

and the corresponding fundamental frequency is obtained using $f = \frac{\omega}{2\pi}$:

$$f_1 = \frac{{\beta_1}^2}{2\pi L^2} \sqrt{\frac{EI}{\rho A}} \tag{3}$$

Substituting β_1 = 4.730 produces $\frac{{\beta_1}^2}{2\pi} = \frac{22.37}{6.283} \approx 1.028$. Thus, the widely used simplified form of the equation becomes:

$$f_1 = \frac{1.028}{L^2} \sqrt{\frac{EI}{\rho A}} \tag{4}$$

The numerical constant 1.028 is not arbitrary; it arises directly from the eigenvalue associated with the fundamental flexural mode of a free–free bar. In the context of Javanese gamelan, this relationship explains why shorter bars, such as those in the peking, generate higher frequencies, whereas longer and thicker bars produce lower fundamental frequencies. The model demonstrates that pitch is determined by the bar's length, material elasticity, density, and geometric configuration, confirming that traditional gamelan craftsmanship inherently applies principles consistent with modern acoustic physics.

The *kenong* and *gong* worked based on the principle of two-dimensional plate vibration. When struck, the metal surface vibrated in complex standing wave patterns. The curved shape and raised center (boss) of the *gong* and *kenong* created an uneven mass distribution, producing distinct fundamental tones and inharmonic overtones. Their low vibration frequencies and long resonance durations explained why the *gong's* sound remained audible for several seconds after being struck.

The acoustic behavior of the *gong* and *kenong* can be described using the classical vibration model of thin circular plates. When struck, the metal plate vibrates in two-dimensional standing-wave patterns whose frequencies depend on the plate's thickness, radius, and elastic properties [19]. This behavior is represented by the general modal frequency equation for a circular plate:

$$f_{mn} = \alpha_{mn} \frac{h}{a^2} \sqrt{\frac{E}{12\rho(1-v^2)}} \tag{5}$$

where h is the plate thickness, a is the radius, E is Young's modulus, ρ is material density, v is Poisson's ratio, and α_{mn} is the mode constant determined by the boundary conditions. For the fundamental mode of a free-edge circular plate, the value is approximately α_{01}, almost equal to 10.21.

This equation shows that the fundamental frequency decreases as the plate radius increases and increases with plate thickness and material stiffness. In the context of Javanese gamelan, the large radius and curved shape of the gong produce low-frequency vibrations with long sustain. At the same time, the raised boss redistributes mass and shifts the vibrational pattern, resulting in the characteristic deep, resonant, and slightly inharmonic sound unique to the gamelan ensemble.

Meanwhile, the *kendang* demonstrated the principle of a vibrating circular membrane. The goat skin stretched across the jackfruit-wood cylinder vibrated when struck. The frequency of the produced sound depended on the membrane's tension and surface mass density. The tighter the skin, the higher the resulting pitch. Variations in striking position, whether at the center or the edge, created different vibration modes and produced diverse timbres.

The acoustic characteristics of the kendang can be explained using the vibration model of a stretched circular membrane. When struck, the membrane produces standing-wave patterns whose frequencies depend on the membrane radius, surface mass density, and the tension applied to the skin. The modal frequencies of a circular membrane are given by the general expression:

$$f_{mn} = \frac{x_{mn}}{2\pi R} \sqrt{\frac{T}{\sigma}} \tag{6}$$

where R is the membrane radius, T is the tension force applied to the skin, σ is the surface mass density, and χ_{mn} is the Bessel-function root corresponding to the vibration mode (m,n). This equation shows that increasing membrane tension raises the vibration frequency, while increasing membrane mass or radius lowers it. In *kendang* construction, variations in how tightly the goat skin is stretched directly influence pitch height and tonal brightness. Additionally, striking the center or the edge selectively excites different membrane modes, producing the diverse timbres characteristic of kendang performance in the gamelan ensemble.

These phenomena showed that the physics system of the gamelan naturally represented basic physics concepts taught in schools, such as the relationship between frequency and the length of vibrating objects, energy damping, resonance, and sound interference.

Analysis of the Relationship between Ethnophysics Phenomena and the Cultural Meanings Underpinning Gamelan as Indigenous Knowledge

This section presents findings related to the second research question, which sought to analyze the relationships between these physics phenomena and the cultural meanings that underpinned gamelan as a form of indigenous knowledge. The findings indicated that the physics phenomena within the gamelan could not be separated from the Javanese worldview of balance, harmony, and spirituality [21].

According to interviews with the *empu gamelan* (gamelan craftsman), the process of making a gamelan was not only aimed at producing physically accurate sounds but also at building the "soul of sound" so that each tone had *rasa* (feeling or emotional resonance). The empu explained that the metal used had to be "alive," meaning it had to vibrate evenly without producing harsh tones. For the craftsman, the vibration of metal symbolized the vibration of human life; the more balanced the vibration, the more harmonious the life. This perspective aligns with broader theories in ethnomusicology, which view gamelan sound as operating simultaneously at physical, emotional, and spiritual levels within Javanese cultural expression [22].

One *pengrawit* explained that within a gamelan ensemble, each instrument had a unique meaning and complementary function, much like the relationships among people in Javanese society. For instance, the *saron* was regarded as the *pamurba irama* (the rhythm regulator), which maintained the overall balance of tempo and harmony. Physically, the saron produced medium frequencies with stable amplitude, serving as a reference for the resonance of other instruments. Symbolically, it represented inner stability and balance, reminding the player to maintain harmony between enthusiasm and calmness [23].

The *demung*, with its lower frequencies and deeper tones, was often interpreted as a symbol of steadfastness and wisdom. Its sound filled the lower harmonic space, reinforcing the ensemble's musical foundation. From a physics perspective, its longer and heavier metal bars produced lower fundamental frequencies, resulting in a warm, mellow sound. Culturally, the demung symbolized the element of earth, representing patience and stability in life [24].

The *peking*, which produced the highest pitch and shortest resonance, symbolized vitality and youthful energy. The *pengrawit* described the peking as "the voice of youth," being bright, fast, and spirited—providing energy to the entire ensemble. This interpretation emphasizes that the relationship between a performer and their instrument is not merely technical but also emotional and symbolic, as the player's body transmits and experiences the energy of sound [25].

The *gong* held the highest spiritual significance within the ensemble. Its low frequency and long resonance demonstrated large amplitude and slow energy decay, which, in Javanese cosmology, symbolized the universe and eternity. The first stroke of the gong marked the beginning of life, while the last marked its end, signifying the cyclical nature of existence [21]. The gong's physical vibration is often described as producing a transcendental effect that resonates with both performers and listeners, a phenomenon referred to as spiritual sonority [22].

The *kendang*, as the rhythm controller, represented the soul and dynamism of life. In physics terms, variations in skin tension and striking position produced multiple vibration modes, resulting in diverse timbres. Culturally, the *kendang* symbolized the *pamomong* (guardian or guide), the one who ensured that all instruments played harmoniously and prevented their sounds from colliding, either physically or symbolically [23].

Overall, the sound of gamelan represented the integration between the physics of vibration and resonance and the Javanese philosophy of harmony. This relationship demonstrated that science and culture were not separate domains but rather mutually illuminating forms of knowledge. Gamelan is understood as a living cultural body in which the physics of sound, aesthetic expression, and spirituality coexist as a unified system of meaning [25].

Thus, the study of ethnophysics in gamelan revealed that concepts such as vibration, resonance, and frequency could be interpreted not only scientifically but also as symbols of life, social harmony, and spiritual balance. This connection illustrated how the physics of vibration evolved into a philosophy of harmony, making the gamelan a genuine bridge between science and culture.

Pedagogical Implications for Designing Culturally Responsive STEAM-Based Physics Learning

This section discusses the pedagogical implications derived from the ethnophysics analysis of Javanese gamelan for the development of culturally responsive, STEAM-based physics learning models. The findings suggested that integrating the ethnophysics of gamelan into physics education could promote learning experiences that are creative, inclusive, and contextually meaningful for students.

The study demonstrated that the physics concepts embedded in gamelan, such as vibration, resonance, frequency, and energy transfer, could serve as authentic contexts for learning. By observing how the *saron*, *demung*, and *peking* produce different tones according to the length and thickness of their bars, students can explore the relationships among frequency, wavelength, and material properties through real cultural artifacts. This contextual approach encourages learners to view physics not as abstract formulas but as knowledge deeply connected to their local heritage and lived experiences. Such integration aligns with the principles of place-based science education, which situates learning within learners' own cultural and geographical environments [4]. The integration of gamelan into physics learning naturally encompasses all elements of STEAM within a coherent educational experience, as shown in Table 1 below.

Table 1. Integration of STEAM Components in the Context of Javanese Gamelan.

STEAM Component	Representation in Gamelan Context	Learning Application
Science	Concepts of vibration, frequency, resonance, and sound waves.	Students measure sound frequencies using mobile applications and analyze vibration patterns in different instruments.
Technology	Traditional metal forging, tuning techniques, and the use of modern measurement tools.	Compare traditional tuning methods with digital tuners to examine precision and sound quality.
Engineering	Design of instrument frames, placement of bars, and resonating cavities.	Students design simple prototypes of metallophones or drums and test how material and shape affect sound.
Arts	Aesthetic design, musical expression, and cultural symbolism of gamelan tones.	Compose short musical patterns combining physics-based sound experiments and cultural creativity.
Mathematics	Ratios between bar length and frequency, interval relationships in tuning systems.	Students calculate proportional relationships between bar dimensions and pitch differences.

Through this framework, students engage in interdisciplinary exploration that connects analytical reasoning with artistic and cultural appreciation. The approach encourages not only conceptual understanding but also creative synthesis, a hallmark of 21st-century STEAM education [2].

Learning through gamelan-based ethnophysics also enhances creativity and inclusivity. Students are invited to create, test, and refine sound-producing models, mirroring the empirical methods of traditional gamelan makers. This hands-on inquiry fosters creative problem-solving, aligning with the principles of project-based learning [18].

Moreover, by positioning cultural heritage as a source of scientific learning, the approach acknowledges the diverse epistemologies of students, particularly in multicultural contexts. It empowers learners to value their cultural background as part of scientific discourse, supporting the goals of decolonizing science education [25]. Such inclusivity allows students who may not traditionally identify with science to find personal meaning through culturally grounded learning experiences.

The integration of Javanese gamelan into physics learning exemplifies a culturally responsive pedagogy, in which local culture serves as both the content and the medium of scientific exploration. Teachers can use gamelan not only as a learning tool for sound and vibration but also as a framework for discussing broader themes such as harmony, balance, and sustainability. These values parallel both physics and cultural systems.

This pedagogical model supports the philosophy of Merdeka Belajar (Freedom to Learn), encouraging autonomy, contextualization, and creativity in education. Students learn physics through observation, experimentation, and reflection grounded in their own cultural identity. Thus, gamelan-based ethnophysics can serve as a bridge between traditional wisdom and modern innovation, preparing students to think critically and act creatively in a culturally diverse and technologically advancing world.

Theoretical and Educational Significance

This study provided both theoretical and educational contributions to the field of culturally responsive science education. Theoretically, it bridged two paradigms that have often been treated separately: indigenous science, which is grounded in local wisdom and embodied cultural practices, and modern STEAM education, which emphasizes creativity, interdisciplinarity, and innovation. By analyzing the ethnophysics of Javanese gamelan, the research demonstrated that traditional knowledge systems inherently contain scientific reasoning consistent with with fundamental physics concepts in contemporary science education, such as vibration, resonance, and frequency.

From an educational perspective, the study proposed a conceptual framework called Ethno-STEAM, a model of physics learning that integrates cultural heritage within the interdisciplinary domains of science, technology, engineering, arts, and mathematics. This framework encourages students to perceive scientific inquiry as part of human creativity, craftsmanship, and identity rather than as an abstract and culture-free endeavor. It establishes a pathway for transforming traditional arts into living laboratories of science where learners can explore, experiment, and innovate while remaining grounded in their cultural environment.

Moreover, the findings contributed to the ongoing movement toward decolonizing science education, in which indigenous knowledge is recognized as a legitimate source of scientific and pedagogical innovation. By positioning Javanese gamelan as both a subject of scientific investigation and a medium of cultural expression, this study illustrated how local traditions can inform global educational paradigms that value diversity, inclusion, and sustainability. Through this framework, ethnophysics in Javanese gamelan reveals the scientific essence of traditional art and offers a transformative model for future STEAM-based physics learning, grounded in cultural identity and sustainability.

This study also strengthens the theoretical foundation of physics education by demonstrating how mathematical modeling can be applied to traditional musical instruments. Through the use of established formulations such as the Euler–Bernoulli beam equation, plate vibration theory, and circular membrane models, the research provides a scientific explanation of gamelan acoustics that aligns with fundamental principles in wave mechanics and classical acoustics. This integration of ethnophysics and mathematical modeling enriches the disciplinary understanding of vibration, resonance, and sound propagation, positioning indigenous instruments as valid and rigorous tools for teaching core physics concepts.

Limitations and Future Works

This study is limited by its qualitative scope, which involved a relatively small number of gamelan practitioners and focused only on six types of instruments within one workshop and one art group. The acoustics analysis relied primarily on theoretical modeling, with no laboratory-based measurements to validate the numerical estimates. Future research may expand the sample of cultural practitioners, incorporate comparative studies across different gamelan styles (such as Banyumasan or Balinese gamelan), and employ experimental acoustic analysis or digital simulations to strengthen the empirical grounding of ethnophysics. Additionally, further development of the Ethno-STEAM model can be explored through classroom trials, design-based research, and its integration into national curriculum frameworks.

CONCLUSION

This study examined the ethnophysics characteristics of Javanese gamelan and analyzed their potential integration into STEAM-based physics learning. The findings show that each instrument, including the saron, demung, peking, kenong, gong, and kendang, embodies fundamental physical principles such as vibration, resonance, frequency, amplitude, and damping. By applying established theoretical models, including the Euler–Bernoulli beam equation for vibrating bars, the plate-vibration model for gongs and kenong, and the circular membrane equation for kendang, the study demonstrates that the acoustic behavior of gamelan instruments can be rigorously explained through contemporary physics analysis. These results confirm that traditional gamelan craftsmanship closely aligns with scientific principles and reflects empirically refined knowledge systems across generations.

In addition to their scientific dimensions, gamelan instruments carry cultural and philosophical meanings rooted in Javanese cosmology that emphasize harmony, balance, and interconnection. The coexistence of physical principles and cultural symbolism illustrates that science and culture function as complementary ways of understanding natural phenomena. Through this perspective, gamelan can be viewed not only as a musical heritage but also as a cultural medium that embodies empirical reasoning, aesthetic expression, and spiritual values.

The findings of this study highlight the pedagogical potential of integrating ethnophysics into STEAM education, enabling creative, inclusive, and contextually relevant learning experiences. Connecting physics concepts with local cultural heritage can strengthen students' scientific literacy while fostering cultural identity. The Ethno-STEAM framework proposed in this study demonstrates how traditional arts can serve as interdisciplinary learning platforms that support observation, experimentation, design, creativity, and cultural reflection. This approach aligns with Merdeka Belajar's goals and contributes to ongoing efforts to decolonize science education by recognizing indigenous knowledge as a valid foundation for scientific inquiry.

In conclusion, the ethnophysics of Javanese gamelan reveals the scientific essence embedded within traditional art and offers a meaningful model for future physics learning. This model is scientifically rigorous, culturally grounded, and capable of supporting sustainable and innovative educational development.

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