

Exploration of Sound Wave Concept in the Making and Playing of Yogyakarta Gamelan: STEM Learning Approach

Rika Tri Intan Lestari*, Sudi Dul Aji, and Akhmad Jufriadi

Science Education, Universitas PGRI Kanjuruhan Malang, Malang, Indonesia

*rika.tri.intan.23@gmail.com

Article Info	Abstract
Article history: Received: June 12, 2025 Accepted: July 18, 2025 Published: November 5, 2025 Keywords: Ethnomusicology Gamelan Yogyakarta Material Sound wave This article is licensed under a creative commons attribution-share alike 4.0 international license © 2025 Jurnal Ilmiah Pendidikan Fisika	This study explores the concept of sound waves in the making and playing of Yogyakarta gamelan through a STEM (science, technology, engineering, and mathematics) learning approach, addressing the urgent need for scientific documentation amid the declining sustainability of this cultural heritage. Using a descriptive qualitative method with a case study design, the research examines the material composition, forging techniques, and acoustic properties of gamelan, incorporating insights from four experienced gamelan craftsmen and a gamelan practitioner (wiyaga) in Yogyakarta. Findings reveal that the optimal bronze composition (a 77:23 copper-tin ratio) and traditional manufacturing processes significantly influence sound characteristics, such as sustain, harmonic richness, and tonal depth, aligning with principles of material physics (Young's modulus, density, and damping coefficient) and vibration mechanics. Despite practitioners' reliance on empirical knowledge, their techniques demonstrate an implicit understanding of STEM concepts, particularly in tuning and sound optimization. However, a disconnect remains between scientific terminology and traditional practice, highlighting the need for culturally sensitive STEM integration in gamelan education. The study concludes that a holistic STEM approach can bridge scientific and cultural perspectives, supporting both the preservation of Yogyakarta gamelan and innovative educational models. Recommendations include STEM-based training for artisans and further research on alternative materials while preserving traditional sound aesthetics.
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INTRODUCTION

Yogyakarta gamelan, more than just a musical ensemble, is an important node of Javanese culture that connects philosophical, aesthetic, and collective identity values (Hananto, 2020). However, this intangible legacy faces complex sustainability challenges. The data shows an alarming trend: about 35% of the 1,200 types of traditional Indonesian musical instruments, including various forms of gamelan, are increasingly rare in cultural practices. The situation in Yogyakarta itself shows symptoms of knowledge extinction, where only about 120 active artisans remain, and the majority (70%) are over 50 years. This threat is increasingly evident given the limited systematic scientific documentation, especially in uncovering the fundamental relationships between materials, working techniques, and the characteristics of the sound waves produced (Kholidah, 2023; Nuryadi & Kholifa, 2020).

Sound waves, as one of the fundamental physical concepts, play a crucial role in understanding traditional musical instruments, including the Yogyakarta gamelan. The majority of gamelan makers (approximately 85%) still rely heavily on hereditary wisdom,

without the support of comprehensive acoustic analysis, to understand, for example, how metal composition or forging techniques affect natural frequencies, harmonization, or sound sustain ([Slamet et al., 2019, 2021](#)). This lack of scientific understanding has implications for significant variations in sound quality between products, even for similar instruments ([Erlangga et al., 2022](#)), a crucial problem amid the increasing demand for gamelan for performance and educational needs ([Idrus, 2022](#)).

Meanwhile, existing research on Yogyakarta gamelan is often fragmented in its approach. In-depth studies are mostly directed at historical, social, or aesthetic aspects ([Nurhadi, 2018](#); [Setianingrum et al., 2023](#)), while science-based explorations, such as acoustic analysis, are generally carried out separately and do not touch on the specificity of the Yogyakarta context—such as the composition of bronze and iron materials, unique blade forging techniques, and manual tuning processes (SANJAYA, 2022; Slamet et al., 2019). As a result, a holistic understanding of how the concept of physics, particularly the principle of sound waves, is manifested and managed in the traditional practice of making and tuning Yogyakarta gamelan is still inadequate. This knowledge gap opens up opportunities for alternative approaches that are able to bridge local science and wisdom.

Within this framework, the STEM (science, technology, engineering, and mathematics) approach offers a relevant perspective. UNESCO (2021) reports that 78% of member states have integrated STEM into the national curriculum to improve science literacy and preserve cultural heritage ([Aikenhead & Ogawa, 2007](#); [Idrus, 2022](#)). This approach allows the exploration of sound wave concepts through the side of science (acoustic physics, materials), the use of technology (measurement instruments), the application of engineering principles (engineering the process of blade formation and tuning), and mathematical analysis (quantitative measurement of frequencies and patterns) ([Iswantoro, 2018](#); [Kartika & Zul Hidayatullah, 2020](#); [Nikolić & Said-Houari, 2021](#)). The integration of STEM perspectives with the empirical knowledge of gamelan craftsmen and musicians (ethnomusicology) is believed to result in a richer understanding and support evidence-based conservation efforts, as well as the development of innovative educational models ([Siregar, 2019](#)).

The concept of sound waves in the making and playing of Yogyakarta gamelan not only expands the existing understanding of the relationship between science and culture but also provides a more relevant and engaging learning approach for students ([Damarsha et al., 2024](#); [Murphy et al., 2019](#)). Based on the challenges faced and the potential of the STEM approach, the researcher aims to delve deeper into the composition of the materials used in the making of Yogyakarta gamelan and its implications on the sound, the traditional process or technique of blade making and its impact on vibration and acoustic characteristics, and understand the perspective of practitioners (both craftsmen and craftswomen) about the relationship between the principles of science, especially the concept of sound waves, with their real practice in creating and producing gamelan sounds.

METHODS

This study uses a descriptive qualitative method with a case study design to explore the concept of sound waves in the creation and performance of Yogyakarta gamelan from a STEM perspective. This design was chosen because it provides a deep understanding of acoustic phenomena in a complex cultural context ([Creswell, 2019](#)). Case studies allow researchers to thoroughly analyze the science, technology, engineering, and mathematics aspects involved in the production and performance of gamelan ([Nuryadi & Kholifa, 2020](#)). This approach is also in line with previous research that integrates acoustic analysis with ethnomusicology ([Wrahatnala, 2019](#)). The research subjects consist of four male gamelan craftsmen and one gamelan wiyaga graduate from an art school in Yogyakarta. The criteria

for selecting participants were based on a minimum of 10 years of experience in their field and active involvement in gamelan preservation ([Creswell, 2019](#); [Iswantoro, 2018](#)). This sample selection ensures adequate representation of the gamelan wiyaga perspective. The research process is illustrated in Figure 1.

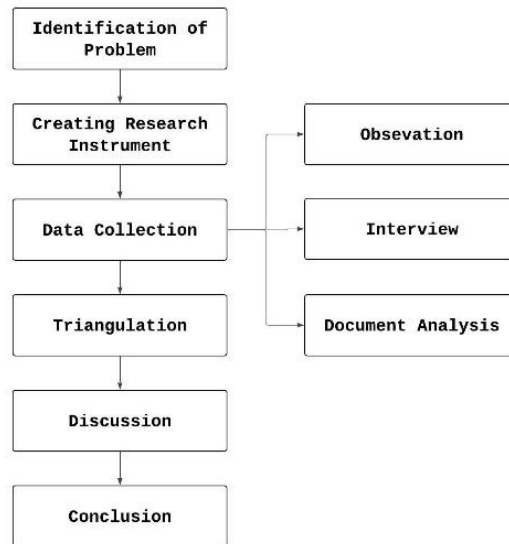


Figure 1 Research flow

Data collection methods included participatory observation and in-depth interviews. The initial stage of this study began with a comprehensive identification of relevant issues that needed to be addressed. Once the issues had been identified, the researchers designed the tools needed for data collection; in this study, interview guides and observation sheets were used. Data collection was conducted in three stages through observation, interviews, and document analysis. Interviews were conducted to obtain information that the researcher could not observe directly, while document analysis was conducted to strengthen the data obtained through observation and in-depth interviews.

The variables studied in this research were material selection, forging process, tempering process, and sound characteristics. Data validity was maintained through triangulation of sources by comparing the results of observations, interviews, and document analysis. Additionally, cross-checking (member checking) was conducted with participants to ensure the accuracy of the data. Primary data sources were obtained through field notes during observations and interview transcripts, while secondary data included historical documents and literature ([Creswell, 2019](#)). All data obtained were then presented in descriptive text, tables, and diagrams, and interpreted to reach conclusions. Furthermore, discussions were conducted with experts to obtain conclusions with a broader scope.

RESULTS AND DISCUSSION

Based on interviews with four gamelan craftsmen in Yogyakarta, it was revealed that there is a connection between STEM and the making of traditional gamelan, but the craftsmen are still unfamiliar with the scientific terms used in science. The composition of materials and the forging process are the primary factors that determine the sound characteristics of the Yogyakarta gamelan. There are also gamelan traditions that are often utilized in the manufacturing process, which can be studied scientifically.

The influence of material composition in the manufacturing process on gamelan sound

The sound quality of Yogyakarta gamelan is highly dependent on the composition of the bronze used. Traditionally, bronze for gamelan consists of a mixture of copper and tin in a ratio of approximately 10 parts copper to 3 parts tin ([Slamet et al., 2021](#)). This mixture produces a metal with ideal acoustic properties. If the tin content is too low, the sound produced will be less clear with short sustain. Conversely, if there is too much tin, the metal becomes brittle, and the sound produced becomes dry with very short sustain ([Slamet et al., 2019](#)). The right composition produces a sound with long sustain and rich harmonics, which is characteristic of Yogyakarta gamelan. Impurities in the metal can interfere with the purity of the sound produced ([Sugita & Astawa, 2016](#)). This is explained further in Table 1.

Table 1 Effect of bronze composition on sound characteristics

Ratio (Cu:Sn)	Sifat Material	Sound Impact	Acoustic Quality
85:15	Soft, elastic	Short sustain, unclear tone	Limited harmonics, high damping
77:23	Optimal hard-elastic	Sustain long, harmonic-rich	Complex timbre, low damping
70:30	Hard-brittle	Very short sustain, dry-produced tone	Harmonic sinking/muffling, very high damping

The Role of Science (Material Physics in Resonance and Sustain)

From the point of view of acoustic physics, there are three main parameters of materials that affect the sound of gamelan:

- Young's Modulus: Indicates the material's rigidity. Bronze with a lead content of 23% has a Young modulus of about 110 GPa, which affects the propagation speed of sound waves and the basic frequency ([Kartika & Zul Hidayatullah, 2020](#)).
- Density: Bronze has a density of about 8,800 kg/m³, which contributes to the heavy sound character ([Irawan, 2020](#); [Nuryadi & Kholifa, 2020](#)).
- Damping coefficient: Bronze for gamelan has a very low damping coefficient, allowing for long sustains of up to tens of seconds on large instruments such as gongs ([Raharja & Darmawan, 2021](#)).

More clearly the relationship of material physical science to the resulting resonance is written more systematically in Table 2.

Table 2 Physical properties of typical yogyakarta sound support materials

Parameter	Bronze	Iron	Teak wood	Impact on sound
Modulus Young (E)	110 Gpa	200 Gpa	10-1 Gpa	Determining pitch and transient response
Density (ρ)	8,800 kg/m ³	7,870 kg/m ³	700 kg/m ³	Gives heavy voice characters
Damping Coefficient	0.001-0.005	0.01-0.03	0.05-0.1	Long sustain when the value is low.

The Role of Technology and Engineering (The Manufacturing Process and its Influence on Acoustics)

The process of making traditional Yogyakarta gamelan is designed to optimize the properties of materials through special techniques:

- Casting is carried out by pouring molten metal into clay molds. Proper temperature control prevents internal defects that can impair sound quality ([Sugita & Astawa, 2016](#)).

- Gradual forging changes the microstructure of metal crystals, improving homogeneity and reducing internal defects ([Ariyanto & Hananto, 2014](#)).
- Turning is done with high precision, where thickness inconsistency of more than 0.3 mm can cause pitch problems.
- Tuning uses the mathematical principle of plate frequency, where a slight reduction in mass can significantly alter the pitch frequency ([Cahyadiningrat et al., 2023](#)).

The Role of Mathematics (Comparison of Alternative Materials)

Other materials, such as wood and iron, are sometimes used for certain parts, but they have different acoustic characteristics:

- Teak wood with a density of about 700 kg/m³ in the resonator box provides a loud muffling effect at a certain frequency ([Yuliana et al., 2023](#)).
- Iron with a high Young's modulus is used for frames due to its ability to dampen unwanted vibrations.
- Modern bronze with zinc content has a higher damping coefficient, resulting in a shorter sustain than traditional bronze.

In Table 3, it is mentioned in detail between the influence of materials on the aesthetics of the sound of gamelan yogyakarta

Table 3 The impact of materials on the aesthetics of yogyakarta sound

Sound Characteristics	Supporting Materials	The role of STEM
Long sustain	Bronze Sn 23%	Minimal internal damping → Acoustic energy lasts a long time
Rich's harmonic	Structure homogeneous micro	Stable wave superposition (Fourier principle)
Weight, deep	High density ($\rho > 8,500$ kg/m ³)	Large mass → High vibration amplitude
Clear	Metal purity (Cu+Sn >99%)	Regular crystal structure → coherent waves

The material characteristics of Yogyakarta's gamelan, especially the bronze composition, density, modulus of elasticity, and microstructure, interact with the principles of vibrational physics (acoustics) to create its distinctive sound ([Ariyanto & Hananto, 2014](#); [Raharja & Darmawan, 2021](#); [Sartini & Priyanto, 2021](#); [Sugita & Astawa, 2016](#)). Traditional engineering processes (casting, forging, tuning) aim to modify the properties of these materials precisely, supported by hereditary empirical mathematical calculations. The result is a unique balance between long sustain (*lugu*), harmonic richness (*mbung mbung*), and depth of tone (*ngemung*) that is the acoustic identity of Yogyakarta gamelan, distinguishing it from the lighter Surakarta style. This is proof of the integration of science, technology, engineering, and mathematics in the culture of the archipelago.

Gamelan Blade-Making Techniques from a STEM Perspective

The creation of gamelan blades (such as *saron*, *gender*, or *slenthem*) is a complex synthesis of STEM principles. This process combines understanding of metal materials, acoustics, engineering precision, and mathematical calculations to produce an accurately tuned instrument with distinctive sound characteristics. Below explains how STEM can play a role in the technique of making gamelan blades:

1. The Role of Science (Materials and Acoustics)

Traditional Yogyakarta gamelan blades are generally made of bronze (copper-tin mixture) or iron. Actually, from the Yogyakarta *keraton*, there is its own pakem,

but from the scientific side, it can be seen that the selection of this material is based on:

- Acoustic Properties: Bronze (Cu:Sn ratio 80:20) has a low attenuation coefficient, allowing for long sustain and complex overtones. Basic frequency formula (f_0) bar:

$$f_0 \propto \frac{t}{L^2} \sqrt{\frac{E}{\rho}}$$

Description:

t = Thickness

L = Long

E = Modulus Young

ρ = Density

- Heat Treatment: The annealing process (heating to 500–900°C followed by slow cooling) reduces the internal stress after forging and improves the ductility of the metal.

2. Technology and Formation Engineering

The manufacturing process involves forging technology and precision machining:

- Forging: The metal is heated and then hammered/hydraulic machined to create a basic profile (thick in the middle, thin in the end).
- Accurate Sculpting:
- Milling for flat surfaces.
- Turning forms a transverse curve (bow-shaping).

Figure 2 shows a saron that has gone through a long forging and tuning process .



Figure 2 Saron Blade

- Curve Function: Increases structural rigidity and suppresses even vibration mode (f_2 , f_4), resulting in clearer sound.

3. Tuning and Calibration Math

Tone tapping relies on the principles of physics, vibration, and mathematical calculations:

1. Tuning Formula: Frequency change (Δf) when mass is scraped:

$$\Delta f \propto \frac{\Delta m}{m} \cdot f_0$$

2. Scraping Technique:

A U/V pattern at the bottom of the blade (near the tip) serves as a nodal point to maintain the base vibration.

1. If the pitch is too low, the mass (Δm) is reduced by scraping the bottom.
2. If it is too high, the stiffness (E) is reduced by scraping the top surface (rarely done).

4. STEM Integrated: Case Study

To examine the relationship between STEM and the manufacturing process, as seen in Table 4. The following Table 4 summarizes the parameters for making bronze bars for tones (660 Hz):

Table 4 Relationship of bronze blade-making parameters with STEM concept

Parameter	Value	VOTE
Metal Composition	Cu 85% + Sn 15%	Science: Densitas (ρ) $\approx$ 8.8 g/cm ³ , modulus Young (E) $\approx$ 110 GPa
Dimension	Length (L): 30 cm, Center thickness: 9 mm	Engineering: Optimization of t/L^2 ratio for target frequencies
Curve	Radius: 1.5 m	Physics: Press even vibration mode
Early Mass	1200 g	Mathematics: Calculation (Δm) for pitch correction
Pitch Correction (640→660 Hz)	0.5g scraping under the tip	Technology: Use of digital tuner verification

The Perspective of a Gamelan Practitioner

In an interview with a wiyaga graduate of one of Yogyakarta's art colleges who also serves as the director of the Gamelan Center, it was also revealed that the complex dynamics between scientific approaches and traditional wisdom in the gamelan world recognize the benefits of understanding the basics of sound science, such as the function of cloth pads on the saron that play a role in optimizing resonance. However, the tuning process still prioritizes a subjective approach based on experience and ear sensitivity, with the main principle being that the most important thing is how the sound feels. This phenomenon is evident in the tuning of some tones that are deliberately left "*miring*" or imperfect to create a certain character of greget, deviating from conventional acoustic standards.

The concept of ideal sound in Yogyakarta gamelan contains a cultural dimension that is not fully quantifiable. Wiyaga describes sound characteristics that are considered ideal, such as the gong, which must sound gentle yet authoritative; the *kenong*, which is loud but not dry; and the *saron* and *bonang*, which must have a clear resonance, or in local terms, "*mbeneng*". These sound characteristics are achieved through a combination of technical knowledge of materials and an intuitive musical approach, demonstrating how scientific and traditional aspects complement each other in practice.

The tradition of storing new gamelan for one to two years before playing also demonstrates the intersection of acoustic phenomena and local wisdom. From a scientific perspective, this storage period enables the metal material to undergo a natural stress-relief process, which reduces damping and stabilizes the crystal structure, thereby making the gamelan sound more stable (Perlman, 2019). However, for traditional craftsmen/*wiyaga*, this process is understood as a period of 'gamelan soul maturation,' suggesting different interpretations of the same physical phenomenon.

These findings reveal an interesting pattern in the Yogyakarta gamelan ecosystem, where science serves as a tool for understanding acoustic phenomena, while tradition serves as a value framework that shapes sound aesthetics. The creative process of gamelan making and playing occurs precisely at the intersection of these two approaches. The implication for traditional music education is the need to adapt a culturally sensitive STEM approach, where science literacy for gamelan *wiyaga* should focus on basic acoustic concepts most relevant to the field's needs, without ignoring established traditional values.

CONCLUSION

This study successfully uncovered the relationship between the concept of sound waves in the creation and performance of Yogyakarta gamelan through a STEM approach. First, the composition of the material (copper and tin with an optimal ratio of 77:23), as well as traditional firing and forging techniques have been shown to significantly influence the acoustic characteristics of gamelan, such as sustain length and harmonic richness, which is supported by the physical properties of the material, such as Young's modulus, density, and damping coefficient. Second, the gamelan manufacturing process incorporates principles of precision technology and engineering, including casting, forging, and tuning, which aim to optimize sound quality through a combination of mathematical calculations and empirical experience. Finally, the perspective of practitioners (gamelan makers and players) shows that although they are not yet fully familiar with scientific terminology, their traditional practices are in harmony with scientific principles, especially in terms of tuning and sound aesthetics, which combine subjective approaches and local wisdom.

Based on these findings, it is suggested that the STEM approach in gamelan learning be integrated with cultural understanding to maintain the authenticity of traditions while improving science literacy. STEM-based training can be developed to help gamelan craftsmen and artists understand acoustic concepts practically without neglecting the values of local wisdom. Furthermore, additional research can focus on exploring alternative materials or modern techniques that retain the distinctive characteristics of Yogyakarta gamelan.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, SDA&AJ; methodology, SDA&RTIL; formal analysis, RTIL; data collection, RTIL; writing preparation of the original draft, RTIL; editing and revision, RTIL; supervision, SDA.

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AUTHOR PROFILE



Rika Tri Intan Lestari
rika.tri.intan.23@gmail.com
Science education
Universitas PGRI Kanjuruhan Malang



Dr. Sudi Dul Aji, M.Si.
Sudi@unikama.ac.id
Science education, physics education
Universitas PGRI Kanjuruhan Malang
Sinta ID : 164049
Scopus ID : 57200566282



Dr. Akhmad Jufriadi, S.Si., M.Si.
Akhmadjufriadi@unikama.ac.id
Science education, physics education
Universitas PGRI Kanjuruhan Malang
Sinta ID : 6007038
Scopus ID : 57200561257