P-ISSN: 1693-1246
E-ISSN: 2355-3812
June 2026

Jurnal Pendidikan Fisika Indonesia 22 (1) (2026) 46-59
DOI: 10.15294/jpfi.v21i1.35596

http://journal.unnes.ac.id/journals/jpfi

Development and Qualitative Evaluation of A Biomimicry-Enriched Engineering Design-Based Teaching Module on The Sound and Its Properties Unit

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Received: 13 January 2026. Accepted: 25 February 2026. Published: June 2026

Abstract

This study proposes and investigates a biomimicry-enriched, engineering design-based teaching approach for physics. Grounded in situated learning theory, the approach aims to enhance student comprehension and interest by connecting abstract concepts to real-world problem-solving and daily life, a crucial mandate in physics education research. The focus of this research is on the "sound and its properties" unit. The implementation was conducted over 22 class hours, during which students participated in nature-inspired engineering design cycles comprising stages such as problem definition, imagining solutions, identifying sources of inspiration, and modelling. Using a qualitative research design, the study analyzed data from 57 sixth-grade students in Ankara, Türkiye. Qualitative data, collected via students' cooperative group activity sheets, required students to identify biological sources and map similarities between nature and their designs. These data were analyzed through inductive document and content analysis to categorize typical designs and the specific levels of biomimetic mimicry achieved by the groups. The findings provide detailed insights into the students' application of physics principles to design nature-inspired engineering solutions related to sound and its properties.

Keywords: biomimicry, engineering design-based teaching, levels of biomimicry, sound, STEM education.

INTRODUCTION

Physics education research strongly asserts that linking instructional material to students' everyday lives is crucial for improving their grasp of the subject. This emphasis on real-world relevance is supported by several scholars (Foesel & Gehring, 2025; Pilot & Bulte, 2006) because when physics concepts align with students' personal interests and experiences, their overall comprehension is significantly enhanced. To actively engage students within this educational paradigm, innovative teaching strategies like context-based teaching (Echiburu, Hernandez & Pino, 2023; Kaltakci & Eryilmaz, 2011) or engineering design-based teaching has been incorporated into science and physics education (Capobianco, Yu, & French, 2015; Handayani et al., 2024; Korur, Efe, Erdogan & Tunç, 2017; Mohd Shahali, Halim, Rasul, Osman & Zulkifeli, 2016; Zhang, Lin & Oon, 2025).

Recent studies suggest that incorporating biomimicry-the practice of drawing inspiration from nature to solve human challenges—can significantly enhance students' STEM learning experiences (Canbazoğlu Bilici, Küpeli & Guzey, 2021; Gardner, 2012; Kaltakci-Gurel & Gokce, 2025; Pauls, 2017). Biomimicry is considered a highly effective and engaging educational approach because it allows students to apply scientific knowledge in practical contexts, thereby encouraging them to associate scientific concepts with everyday life and helping to bridge the gap between theoretical knowledge and real-world applications. More generally, biomimicry offers a unique way to connect biology, engineering, and education, serving as a sustainable and innovative method for tackling real-world problems. For physics education specifically, it provides students with a creative platform to explore physics concepts in biological contexts and their practical applications in technology and engineering.

This study is grounded in situated learning theory (Lave & Wenger, 1991), which holds that knowledge is not passively acquired but actively constructed within a specific context through real-world experiences, problem-solving, and social interaction. To facilitate effective learning, students should engage in authentic, meaningful activities that are relevant to real-life situations. Real-world challenges provide authentic learning contexts where students can apply their knowledge of science, technology, engineering, and mathematics (STEM). This practical experience boosts their interest in STEM fields and helps them develop a stronger sense of belonging within these disciplines (Chiu et al., 2023). Next-Generation Science Standards (NGSS, 2013) align with situated learning theory by integrating engineering design into science instruction. This approach allows students to apply scientific knowledge to practical problems, promoting deeper understanding and skill development. By providing opportunities for authentic, hands-on learning, the NGSS (2013) promises to enhance student learning outcomes. Integrated STEM education involves exploring the deep connections between the various STEM fields (Aydin-Gunbatar, Tarkin-Celikkıran, Kutucu & Ekiz-Kiran, 2018; Chiu et al., 2023; Honey, Pearson & Schweingruber, 2014; Kelley, Sung, Han & Knowles, 2023). This integrated approach empowers students to tackle complex real-world problems effectively. Educators and policymakers agree on the importance of teaching K-12 students about engineering and its societal impact (Antink-Meyer & Arias, 2022; Barak, Ginzburg & Erduran, 2024; McComas & Burgin, 2020) and several studies have explored pedagogical approaches to teaching engineering in schools.

Consequently, the current study aims to propose a biomimicry-enriched, engineering design-based teaching approach as an innovative model relevant to real-life situations and students' interests. The physics unit on "sound and its properties" was selected for this study because, despite being consistently identified as a challenging concept for learners, there is limited research on effective methods for teaching students about sound and its relevance to their daily lives (Aksoy, Özcan & Çeken, 2023; Aygün & Hacıoğlu, 2022; Faletič, 2023; Tuada & Suparno, 2021). Specifically, this research seeks to bridge the gap between abstract acoustic principles—such as the propagation of waves through different media, the reflection of sound (echo), and the mechanisms of sound insulation—and their functional counterparts in the biological world. By investigating how students identify and apply these specific physics concepts to nature-inspired engineering solutions, the study explores the cognitive transition from understanding biological traits to applying physical laws. Therefore, the research questions are designed to examine how effectively students can map these fundamental physics properties onto their designs through the lens of biomimetic levels.

To understand the outcomes of this novel approach, the present research qualitatively analyzed the sixth-grade students' worksheets to identify the typical designs created by the groups and the natural sources they referenced for their biomimicry-enriched engineering solutions. In biomimicry, to understand an organism, one can investigate its physical form (structure and surface features), its behavioral principles, or its interactions within its “ecosystem”. The quality or level of the biomimicry students perform is a good way to gauge how much they know about the subject. Students show greater biomimetic skill when they replicate an organism's complete set of characteristics—including its form, function, structure, behavior, and interactions in its ecosystem (Volstad & Boks, 2012). Conversely, simply mimicking the organism's form is considered a shallower approach to biomimicry (Qureshi, 2022). In the present study, the students' works were analyzed in terms of levels of mimicking biological systems.

The study aims to answer the following research questions:

- How can a biomimicry-enriched engineering design-based module be developed to effectively facilitate student learning in the "Sound and its Properties" unit?
- What are 6th-grade students' typical designs and/or models in response to biomimicry-enriched engineering design instruction, and what are the sources of inspiration for these designs?
- What are 6th-grade students' levels of mimicking biological systems in biomimicry-enriched engineering design instruction?

METHOD

Research Design

In our previous experimental study (Kaltakci-Gurel & Gokce, 2025), which is the first part of this research, we presented the quantitative results in detail, while the presentation of the qualitative data and the details of the biomimicry-enriched engineering design-based instruction are left to the present study.

In this qualitative study, content analysis was employed to systematically analyze the written work produced by cooperative groups on the biomimicry-enriched engineering design activity sheets. This method involved identifying, categorizing, and interpreting patterns within the textual data to uncover underlying themes and concepts (Miles, Huberman & Saldana, 2020). To answer the research questions, the data gathered from the activity sheets were analyzed inductively using document analysis. Document analysis is a research method that involves the systematic examination of existing documents to extract meaningful data. Two researchers worked together until total agreement was reached; they inductively analyzed the data, developed codes, and grouped the student groups' works into categories for each design activity.

Participants

The sample consisted of 57 sixth-grade students attending a public elementary school in Ankara, Türkiye. This group included 33 female students (57.9%) and 24 male students (42.1%) in two classes.

Instructional Materials and Data Collection Instruments

Lesson plans were developed to support treatment fidelity during the implementation. They served as a guide for the teachers and provided a common instructional structure across the classroom sessions. The stages followed in developing the lesson plans are presented in Figure 1.

The preparation process began with a review of the objectives of the "sound and its properties" unit. After this stage, the researchers examined relevant studies and lesson plan examples focusing on biomimicry and engineering design-based learning. Based on this review, the lesson plans were organized to connect the unit objectives with biomimetic examples and engineering design tasks. Drawing from this review, the researchers developed four biomimicry-enriched engineering design-based lesson plans (activities are detailed in Table 1). In developing these plans, emphasis was placed on integrating contexts and activities featuring biomimicry applications, along with specific engineering design projects. The lessons also incorporated hands-on activities and experiments found in the standard curriculum textbooks. Ultimately, students explored the physics concepts within the unit through a specific biomimetic scenario and were then tasked with designing or creating a nature-inspired model. It is worth noting that for two of the activities ("Towards the Summit" and "Pantograph Making"), students were only required to plan their design, while the remaining two activities required them to create the design or model. Qualitative data were collected through activity sheets obtained from the participants, which were part of these prepared lesson plans.

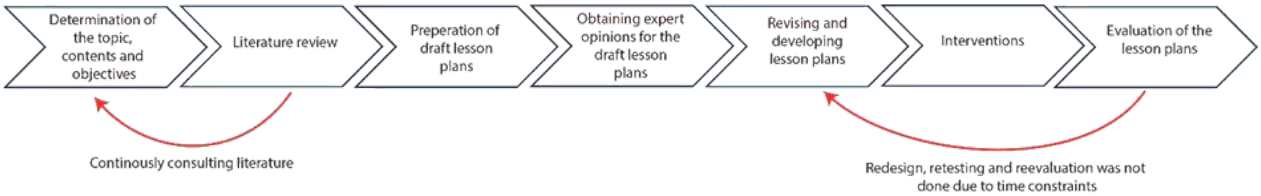

Figure 1. Development Process of Lesson Plans (Reproduced from Roobeek (2019))

Table 1. Biomimicry-Enriched Engineering Design Activities

Biomimicry Contexts	Biomimicry Scenarios	Design Activities
Oilbirds and Effects of Noise Pollution on Communication	Increasing noise pollution due to the increasing number of people day by day negatively affects animals. The communication of animals is endangered due to intense noise pollution. For example, with the increase in transportation between continents, it is difficult for dolphins to communicate with each other. Research shows that the communication of oilbirds is negatively affected by intense noise. To find their way around, these species make loud crunching noises and listen to the echoing sound of hitting objects around them. These birds have developed different song styles to make themselves heard over this intense noise. *Probing questions:* - How do dolphins, whales, oilbirds and moles, which manage to escape predators despite being blind, communicate? - Where can we use the methods these creatures use to survive, reproduce, and find food?	*Towards the Summit* Conditions in high mountains are harsh. Mountaineers tackling the highest peaks need special inventions to accomplish their challenging ascents. Climbers have poor visibility due to clouds. Therefore, they may fall or get lost. They use technological devices to avoid falling and getting lost in cloud-covered areas. So, imagine you are a climber and design your own climbing equipment to solve this bad visibility problem.
Ant Galleria and Musical Instruments	One of Ahsen's favorite activities was walking in nature. One Sunday, Ahsen went for a walk and started to hear whistling sounds. Although no one was around, Ahsen followed the sounds and realized that they were coming from a plant. She immediately used the app on her phone to learn the characteristics of the plant. She learned that this plant, called whistling acacia, has hollow balls called “ant galleria” at the base of its thorns and that ants live in these balls. She learned that the hollow ones without ants make a whistle-like sound when the wind blows. *Probing questions:* - What do you think might be the reason why empty galleys produce sound while full galleys do not? - What design do you think people could have used this situation for? - Which design would you be inspired by?	*Time For Some Music* The band you formed with your friends had to prepare for the end-of-year concerts. But the cost of buying the instruments you need to make music is way out of your budget. Your band needs instruments that can make different sounds using different sound sources and environments, and you need to design your own instruments inspired by other living things. So, design your own musical instrument to solve your problem.
Owls and Fast Trains	In 1990, trains in Japan made a noise similar to an explosion as they traveled through tunnels at 210 kilometers per hour. The train was giving off some of its energy as it sped along. Fortunately, an	*Pantograph Making* Japanese engineers and scientists faced a major problem when designing bullet

Biomimicry Contexts	Biomimicry Scenarios	Design Activities
	engineer named Nakatsu was an avid birdwatcher and studied his feathered friends to find a solution to the noise. When Nakatsu invented the bullet train, he was inspired by owls, penguins, and the moorhens to make it quieter and faster. *Probing questions:* - What is the problem in the text above? - What characteristics of these creatures inspired Nakatsu to solve the problem? - Make a connection between the characteristics of these creatures and the silent speed of the bullet train.	trains: Noise. Until the train reaches a certain speed, the noise is caused by the friction of the wheels on the rails. But when the speed of the train reaches 200 kilometers per hour, the real noise comes from the movement of the train through the air. The most obvious reason for this noise is the pantographs used to receive electricity from the wires above. A pantograph is a device mounted on the roof of vehicles such as trains, trams, or trolleybuses, used to collect electrical energy through contact with the upper catenary wire. In order for a high-speed train to move at high speeds without causing noise, design a pantograph by researching which creatures in nature Japanese engineers and designers were inspired by.
Echolocation of Bats and the Visually Impaired	Echolocation (biosonar) is a method used by many creatures in nature, especially bats. Like bats, some visually impaired people can use echolocation to sense their surroundings. Now researchers are trying to understand this process in depth, which could one day be a useful technique for the visually impaired. One of the people who uses echolocation is Daniel Kish. Daniel is so adept at it that he can sketch a room by making special sounds with his mouth and can mountain bike on unfamiliar trails. This phenomenon of the visually impaired is also seen in some animals. It is known that bats, which have very poor night vision, use echolocation to catch their prey, and submarine creatures use echolocation to navigate when they are in places where they cannot see in the dark. *Probing questions:* - Can we use this echolocation study of visually impaired people using bats as an example in other cases? - Can human beings measure the depth of a dark place under the sea that they cannot see? - How does the sonar device used by fishermen locate schools of fish? - How does the ultrasound device used in medicine work? - Research where these technological devices are inspired from. - What are the similarities between technological devices and the creatures they are inspired by?	

Biomimicry Contexts	Biomimicry Scenarios	Design Activities
Mimar Sinan and his work, the Süleymaniye Mosque	The construction of the Suleymaniye Mosque, which was built by Suleiman the Magnificent under the direction of Mimar Sinan in 1550, was completed in 1557 together with its complex. For 7 years, Sultan Suleiman was curious about the reason why the mosque was not finished, and he went to inspect the mosque, curious about the rumors spreading through the streets. Sinan the Architect is sitting under the dome in the center of the mosque and smoking a hookah. “Great Sinan! What is this?” Sultan Süleyman asks. Mimar Sinan: “Sultan, I keep this hookah here only for its bubbling. There is no tobacco. I am checking how long the sound made by the water bubbles when I blow it spreads in the dome.” *Probing question:* -Which creature do you think Mimar Sinan was inspired by in using the reflection, absorption, insulation, and acoustic properties of sound in those times when there were no loudspeakers?	*Soundproofed Environment* Owls move silently as they fly towards their prey. The main reason why owls can fly much more silently than other birds is related to three characteristics of the feathers on their wings. The feathers on the front of the wing are arranged neatly like the teeth of a comb, the feathers on the back of the wing are flexible, soft, and spaced apart, and the velvety soft feathers on the top of the wings. Based on the feather structure of the snowy owl, sound-absorbing acoustic curtains and panels are designed to provide privacy during meetings in open offices and to prevent intense echo and noise. Design an acoustic environment with sound insulation based on these and similar features of creatures in nature.

Implementation Procedure

The biomimicry-enriched engineering design approach was delivered across 22 class hours over four weeks. To maintain instructional fidelity, the lesson plans were implemented by two different teachers, one of whom was the researcher and the other an experienced teacher in both design-based teaching and biomimicry. The two teachers first engaged in extensive discussion regarding the lesson plans and procedures to ensure consistency.

During the lessons, students worked in cooperative groups (4-5 members) using specially redesigned engineering design activity sheets that incorporated biomimicry principles into traditional engineering design cycles. The key objective was to center the design process around nature-inspired resources and ensure that the final products reflected characteristics of these inspirational sources. The activities systematically guided students through a model detailed in Table 2 that included stages such as: problem definition, finding a nature-inspired solution, planning, identifying source-design similarities, modeling, testing, and sharing. Lessons began with the class reading the activity's real-life problem, followed by group discussion and solution proposals, which were monitored by the classroom teacher. Students receive time until the next session to conduct research, refine their plans, and collect materials before presenting their proposals and constructing their models in the following class. A typical classroom is pictured in Figure 2.

Figure 2. Sixth Graders Designing an Acoustic and/or Sound-Proofed Environment Inspired by Nature

Validity and Reliability

To ensure the validity and reliability of the qualitative findings, several rigorous procedures were implemented throughout the study. For internal validity (credibility), the biomimicry-enriched activity sheets—which served as the primary data collection instrument—were developed based on a comprehensive literature review and aligned strictly with the national curriculum objectives for the “sound and its properties” unit. The instruments were then examined by two experts in science education and biomimicry. This expert review focused on the clarity and suitability of the scenarios and probing questions, particularly in terms of whether they could reveal students’ reasoning about physics concepts and biological sources of inspiration.

To support the reliability of the qualitative findings, the student activity sheets were analyzed using inductive content analysis and document analysis. Two researchers first coded the activity sheets independently, considering both the typical design categories and the biomimetic levels represented in the students’ work. The researchers then compared their coding decisions and discussed any differences in interpretation. The final coding scheme was established after agreement had been reached on the codes and categories.

The consistency of the instructional process was also taken into account. Two experienced teachers implemented the same structured lesson plans in the class sessions. This helped ensure that students encountered similar instructional conditions and that their performance could be observed within a comparable teaching framework. To enhance transparency, an audit trail was also maintained. This included information about the development of the lesson plans, the data collection procedures, and the coding definitions used for the form, behavior, and ecosystem levels of biomimicry.

Data Analysis Methods

The qualitative data obtained from the cooperative group activity sheets were analyzed through inductive content analysis and document analysis. The researchers preferred an inductive procedure because the study aimed to identify categories from students’ written explanations and design products rather than applying a fixed coding scheme at the beginning of the analysis. In the first stage, the activity sheets were read several times, and recurring patterns related to the proposed biomimetic designs and the natural models selected by the students were identified. These patterns were then coded and grouped into broader categories to answer the first research question.

In the second stage, the designs were examined in terms of the level of biomimicry represented in students’ work. For this purpose, the designs were coded under three levels: form, behavior, and ecosystem. For example, designs based on the shape or surface features of a biological model were classified as “form”, whereas designs inspired by biological functions, such as echolocation, were classified as “behavior”.

The coding process was carried out by two researchers. They compared their interpretations, discussed disagreements, and revised the codes where necessary until consensus was achieved. The coded data were then presented through tables and frequency charts in order to describe students’ biomimetic design skills and their use of physics concepts.

Table 2. Stages of Biomimicry-Enriched Engineering Design Model

Stages	Description of the Stage
Defining Problem	The problem situation in the scenario given for the design activity is determined.
Imaging Solution	Brainstorming for research and design ideas to solve the identified problem situation.
Identifying an Inspiration Source from Nature	Based on the biomimicry example related to the subject and objective presented earlier in the design task, or information gathered through research, identify the source and its characteristics in nature that can inspire the proposed solution to the problem.
Planning Design/Model	The best of their solutions was selected.
Identifying Similarities between Source and Design/Model	The similarities between the model created to solve the problem and the source of inspiration are identified.

Stages	Description of the Stage
Creating Design/Model	A model is created for solving the problem.
Testing Design/Model	If the developed model is suitable for data collection and analysis, it is used to collect and analyze data, and the results are evaluated.
Sharing Design/Model	Finally, the design task is completed by discussing issues such as the effectiveness of the nature-inspired design in solving the problem and potential areas for improvement.

Ethical Consideration

The study adhered to the ethical standards and was approved by the Institutional Review Board of Kocaeli University (Approval No: E-10017888-100-366857; date: 09.02.2023). Informed consent was obtained from all participants after they were fully briefed on the study's purpose, methods, right to withdraw, and data confidentiality. Data confidentiality was maintained, and all identifying information was anonymized to protect the participants' privacy.

FINDINGS

During the implementations, the students were allowed to use and fill out the activity sheets on biomimicry-enriched engineering design activities. These activity sheets were used as a data source to qualitatively examine the cooperative group work of the participant students to address the research questions. From the content analysis of the students' written performances on the sheets, we grouped some typical designs/models and their corresponding source of inspiration from nature for each design activity performed during the study. These findings were summarized in Table 3. The findings show that the groups' designs and their sources of inspiration from nature were diverse and creative after a biomimicry-enriched engineering design teaching module.

For the examination of the second research question, students' group work was categorized according to (Qureshi, 2022). It's three levels of mimicking biological systems: form, behavior, and ecosystem. Table 4 shows levels of biomimicry, along with their definitions and samples from students' group work. To understand an organism, one can investigate its physical form (structure and surface features), its behavioral principles, or its interactions within its ecosystem. The quality or level of the biomimicry students perform is a good way to gauge how much they know about the subject. Students show greater biomimetic skill when they replicate an organism's complete set of characteristics-including its form, function, structure, behavior, and interactions in its ecosystem (Volstad & Boks, 2012). Conversely, simply mimicking the organism's form is considered a shallower approach to biomimicry (Qureshi, 2022).

The results shown in Figure 3 reveal that the majority of student groups mimicked the form (n=8) and behavior (n=15) of the organisms they inspired for their designs; however, a very limited number of groups mimicked the ecosystem (n=3). A noticeable difference was observed among the biomimicry activities, where most groups (n = 18) inspired by nature when they were required to create the design or model ("Time for Some Music" and "Soundproofed Environment") instead of only planning their designs from nature ("Towards the Summit" and "Pantograph Making").

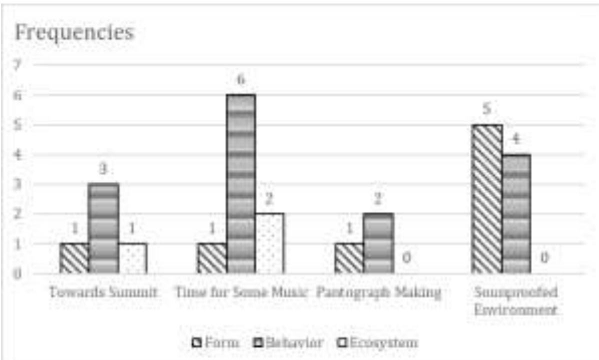

Figure 3. Frequencies of Levels of Biomimicry in Students' Group Works

It is worth noting that for the four different biomimicry-enriched design activities in this study, shown in Table 5, the group members were not static. Therefore, the groups shown with numbers across different activities are not guaranteed to be the same; the numbering is only used for differentiating them. The most common inspiration was taken from the behaviors of organisms, such as the echolocation of bats or dolphins. The second most common inspiration was the form of organisms. Some groups mimicked surface properties, such as the soft nature of owl feathers, while others used structural properties, such as the porous structure of a turtle's shell. Three groups analyzed the ecosystem in which the organism existed. In only one group's work was a complete set of levels of biomimicry (i.e., form, behavior, and ecosystem) included in the same design. This shows that students' biomimetic skills are still not as deep as Volstad and Boks (2012) suggested.

Table 3. Examples of Group Designs and Sources of Their Inspirations from Nature [1,2]

Design Activities	Group Designs/Models	Source of İnspiration for Designs/Models
Towards the Summit	• Smart wristbands *(G1)*, smartwatches *(G2)*, sound sensor shoes *(G3)*, sound sensor glasses *(G4)*, and sound sensor clothing *(G5)* were designed to transmit sound waves through foggy air and receive echoes from a mountain (obstacle).	• In dark caves, bats (*G2*) and grasshoppers (*G1*) navigate by emitting sound waves and listening to the echoes they produce, which help them locate exits and obstacles. • Dolphins and Narwhals send sound waves underwater to locate prey or communicate with others (*G4, G5*). • Rabbits stamping their feet to warn others of danger (*G3*).
Time For Some Music	• Getting different sounds by hitting drums made with empty and full containers (*G1*). • Getting different sounds by allowing air to escape by shrinking the mouths of balloons inflated in different amounts (*G2*). • Producing different sounds by vibrating different rubber bands on stringed instruments (e.g. guitar, violin) made using rubber bands. (*G3*). • Producing sound by shaking a plastic bottle filled with a small number of stones or marbles (*G4*).	• Woodpeckers produce different sounds by pecking at different parts of a tree (*G1*). • Frogs produce different sounds by inflating their throats to varying degrees and slowly releasing air to impress their prey or other frogs (*G5*). • Grasshoppers produce high- or low-pitched sounds by rubbing their hind legs together and vibrating them (*G3*). • Rattlesnakes produce sound by shaking a rattle made up of a series of keratin segments on their tail. They do this to warn their prey or when they feel threatened, causing the segments to rub against each other and create a rattling noise (*G4*).
Pantograph Making	• Reducing noise for high-speed trains by using sound-absorbing materials like cotton and by designing vehicles (pantographs) similar to the flight patterns of silent flying birds (*G1*).	• Owls, along with other silent-flying predator birds, reduce sound energy by absorbing sound through the air spaces between their feathers and by using specialized flight patterns that minimize noise (*G1*).
Soundproofed Environment	• To prevent the sound from inside the theater from escaping, the building is covered with materials that have soft, porous spaces, such as styrofoam. (*G1*). • Covering structures with materials like snow or cotton due to their ability to absorb sound, similar to how snow-covered igloos provide sound absorption (*G2*).	• Penguins escaping predators by silently sliding through snowy environments using their soft, air-filled feathers (*G1*). • When it snows, the porous nature of the surface of snowflakes causes sound waves to be absorbed, resulting in a quiet environment (*G2*).

[1] *G# represents group numbers. Groups may vary across design activities, as new teams are often formed for each activity*

Table 4. Levels of Biomimicry Coding Definitions and Examples

Level of Biomimicry	Definition	*Example from Group Works*
Form	Mimicking an organism's characteristics, specifically its form, which encompasses surface properties like shape, size, color, and material.	Designing a house with a material featuring cavities, mimicking the porous structure of a turtle's Shell. (*surface*) Designing soundproof curtains inspired by the soft and porous nature of owl feathers. (*structural*)
Behavior	Mimicking the underlying principles that drive the organism's function or behavior.	Creating a maraca-like musical instrument filled with different materials, drawing inspiration from how woodpeckers produce different sounds by pecking at different parts of a tree.
Ecosystem	Exploring how the organism interacts with its environment and then mimicking those interactions in the designs.	Creating a musical instrument by sounds produced when air is slowly released from balloons inflated to different sizes by pinching the balloon's neck, inspired by how frogs produce different sounds by inflating their throats to varying degrees and slowly releasing air to impress their prey or other frogs in their environment.

Table 5. Levels of Biomimicry in Group Works

	Toward Summit			Time for Some Music			Pantograph Making			Soundproofed Environment		
Group	Form	Behavior	Ecosystem	Form	Behavior	Ecosystem	Form	Behavior	Ecosystem	Form	Behavior	Ecosystem
1	X	X			X		X	X		X	X	
2		X			X	X		X		X		
3		X	X		X					X	X	
4					X					X		
5				X	X	X					X	
6					X					X	X	

DISCUSSIONS AND IMPLICATIONS

The findings of this study show that a biomimicry-enriched, engineering design-based learning environment meaningfully supports sixth-grade students' understanding of sound and its properties by allowing them to anchor abstract physics concepts to authentic real-world contexts. Most student groups successfully generated nature-inspired designs and were able to articulate the biological principles that informed their engineering models. This aligns with earlier work demonstrating that contextualized and design-based science instruction deepens conceptual understanding by promoting relevance, authenticity, and active engagement (Capobianco, Yu & French, 2015; Echiburu, Hernandez & Pino, 2023). In particular, students' frequent use of echolocation principles from dolphins, bats, and oilbirds indicates that the biomimetic scenarios effectively helped them transfer knowledge of sound propagation, reflection, and interaction with matter into plausible technological solutions. These outcomes echo prior research showing that biomimicry enhances students' ability to connect STEM ideas to real-world innovations (Canbazoğlu Bilici, Küpeli & Guzey, 2021; Gardner, 2012).

Analysis of the levels of biomimicry indicated that most designs reflected form and behavior, while ecosystem-level reasoning was relatively rare. This is consistent with (Qureshi, 2022) observation that novice learners tend to replicate surface features rather than complex ecological interactions. Similarly, (Volstad & Boks, 2012) argue that deeper biomimetic reasoning requires integrating multi-level biological insights, which typically develops with experience. The present findings suggest that while students were highly capable of identifying functional analogies, such as silent owl flight or frog vocalization mechanisms, few were yet able to conceptualize how organisms operate within entire ecological systems. Still, the presence of several ecosystem-level examples demonstrates that the instructional model supported progression toward more sophisticated biomimetic thinking.

Behavior-level mimicry was the most frequently observed level in the students' designs (n = 15). This suggests that students tended to focus on biological functions and processes, such as echolocation or the movement of a rattlesnake's tail, rather than only on visible biological forms. In the context of the sound unit, such examples were closely related to physical processes, including sound production, transmission, reflection, and detection. For instance, designs inspired by bat echolocation showed that students could connect a biological process with the idea of sound waves being emitted and reflected. Therefore, behavior-level biomimicry may offer a productive way for middle school students to relate biological examples to engineering functions and physics concepts (Stevens, Whitehead & Singhal, 2022).

Form-level mimicry appeared in eight designs. Students used structural or material features of organisms, including owl feathers, snow, and turtle shells, to develop ideas related to sound insulation or noise reduction. These examples indicate that students recognized links between physical structure and acoustic function. In particular, their references to porosity, air gaps, and absorption suggest that they were not merely copying visible shapes but attempting to explain how structural features contribute to sound-related effects. The prevalence of form mimicry corroborates existing literature, which posits that looking to nature often begins with mimicking geometry and material (Othmani et al., 2022). For novice designers, the physical form is the most accessible layer of biological information. A turtle shell or a feather is a concrete object that can be visualized, drawn, and modeled. However, the study also hints at a crucial distinction between shallow form copying (copying the shape without understanding) and deep form mimicry (copying the shape because it dictates function). The students' ability to articulate why they used porous materials with referencing air gaps and absorption suggests that the instruction successfully scaffolded them toward the latter, preventing the superficial imitation that often plagues introductory biomimicry projects (Stevens, De Vries, Bos & Kopnina, 2019).

Ecosystem-level mimicry was observed less often (n = 3). This limited occurrence may be related to the complexity of systems thinking, which requires students to consider organisms, environmental conditions, and interactions among different components at the same time (Othmani et al., 2022). Since the activities were mainly product-oriented, students may have focused more on individual artifacts than on broader ecological systems. Future activities may therefore need to include more explicit prompts that guide students to consider environmental interactions and system-level relationships.

The findings also showed that activities involving physical model construction led to more diverse and biologically grounded designs than activities based only on planning. This result suggests that hands-on construction can help students connect biological inspiration with engineering reasoning. By building and revising models, students may better recognize how biological structures or functions can be translated into design solutions. Taken together, the findings support the use of biomimicry-enriched engineering design activities as a situated learning context for teaching sound-related physics concepts.

This study highlights several key shifts we can make in physics and STEM education. First, by pairing biomimicry with engineering design, educators can create a natural stepping stone that helps students ground abstract physical laws in their own lived experiences. As sound is often perceived as a difficult topic for learners (Aygün & Hacıoğlu, 2022; Faletič, 2023)the use of nature-inspired scenarios can reduce cognitive barriers by situating sound within familiar biological contexts such as animal communication or silent locomotion. Second, the findings support the increasing emphasis on NGSS (2013) and contemporary STEM integration models that encourage learners to apply scientific principles in solving authentic, real-world problems. The positive engagement observed among students suggests that biomimetic contexts can strengthen STEM identity, interest, and motivation, particularly by highlighting the relevance of physics to technology, engineering, and biology. Furthermore, the distribution of biomimicry levels in student work suggests an instructional need for explicit scaffolding to help learners progress from form-based imitation toward deeper ecological and functional reasoning. Embedding structured prompts that require students to analyze the organism's environment, constraints, and adaptive strategies may help advance their biomimetic thinking. Finally, because students produced more sophisticated work when tasked with building rather than merely planning designs, curriculum developers and teachers should consider incorporating more model creation, prototyping, and iterative testing opportunities in sound instruction, especially when the goal is to foster higher-order problem-solving skills alongside conceptual understanding.

To sum up, teaching physics in contexts that allow students to link physics to their lives in the real world increases their interest in the subject and helps them gain a good understanding of the concepts. Biomimicry-enhanced engineering design-based activities offered a useful way to connect sound-related physics concepts with examples from nature and technology. In the activities, students worked with biological examples such as dolphin echolocation and owl feather-inspired sound insulation. These examples helped them discuss sound propagation, reflection, and insulation through observable biological functions and structures. For instance, echolocation provided a concrete context for thinking about reflected sound waves, while owl feathers helped students consider how structural features may contribute to noise reduction.

CONCLUSION

In conclusion, this study demonstrates that teaching physics through biomimicry-enhanced engineering design-based activities effectively bridges the gap between abstract concepts and real-world applications. By linking acoustic principles to biological examples, these activities increase student engagement and facilitate a deeper understanding of sound. While the results are promising, the study's reliance on written activity sheets and its focus on a single school unit limit the generalizability of the findings regarding long-term retention and individual learning progression.

Based on these results, several practical recommendations are proposed to improve physics instruction. First, physics educators should integrate multi-level biomimicry tasks that move beyond physical form to functional behavior, as this helps students conceptualize abstract topics like sound waves through tangible, real-world problem-solving. Second, curriculum designers should develop design-based activities that explicitly link biological solutions, such as echolocation or natural insulation, to physical laws to enhance student motivation and knowledge retention. Finally, it is recommended that future researchers incorporate longitudinal designs and qualitative methods, such as interviews and classroom observations, to provide a more nuanced understanding of how students build lasting connections between physics and nature during instruction.

REFERENCES

Aksoy, Ş., Özcan, H., & Çeken, R. (2023). Ses ve Özellikleri ile İlgili Tasarım Temelli Etkinliklerin 6. Sınıf Ögrencilerinin Başarı ve Tutumlarına Etkisi. *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi*, *56*, 555–581. https://doi.org/10.53444/deubefd.1217639

Antink-Meyer, A., & Arias, A. M. (2022). Teachers' Incorporation of Epistemic Practices in K-8 Engineering and Their Views About the Nature of Engineering Knowledge. *Science & Education*, *31*(2), 357–382. https://doi.org/10.1007/s11191-021-00265-4

Aydin-Gunbatar, S., Tarkin-Celikkiran, A., Kutucu, E. S., & Ekiz-Kiran, B. (2018). The influence of a design-based elective STEM course on pre-service chemistry teachers' content knowledge, STEM conceptions, and engineering views. *Chemistry Education Research and Practice*, *19*(3), 954–972. https://doi.org/10.1039/C8RP00128F

Aygün, M., & Hacıoğlu, Y. (2022). Teaching the Sound Concept: A Review of Science and Physics Education Postgraduate Theses in Turkey. *Athens Journal of Education*, *9*(2), 257–276. https://doi.org/10.30958/aje.9-2-5

Barak, M., Ginzburg, T., & Erduran, S. (2024). Nature of Engineering: A Cognitive and Epistemic Account with Implications for Engineering Education. *Science & Education*, *33*(3), 679–697. https://doi.org/10.1007/s11191-022-00402-7

Canbazoğlu Bilici, S., Küpeli, M. A., & Guzey, S. S. (2021). Inspired by nature: An engineering design-based biomimicry activity. *Science Activities*, *58*(2), 77–88. https://doi.org/10.1080/00368121.2021.1918049

Capobianco, B. M., Yu, J. H., & French, B. F. (2015). Effects of Engineering Design-Based Science on Elementary School Science Students' Engineering Identity Development across Gender and Grade. *Research in Science Education*, *45*(2), 275–292. https://doi.org/10.1007/s11165-014-9422-1

Chiu, T. K. F., Ismailov, M., Zhou, X., Xia, Q., Au, C. K., & Chai, C. S. (2023). Using Self-Determination Theory to Explain How Community-Based Learning Fosters Student Interest and Identity in Integrated STEM Education. *International Journal of Science and Mathematics Education*, *21*(S1), 109–130. https://doi.org/10.1007/s10763-023-10382-x

Echiburu, M., Hernández, C., & Pino, M. (2023). Teaching physics in real-life contexts: The Beirut explosion. *Physics Education*, *58*(2), 025009. https://doi.org/10.1088/1361-6552/acad5b

Faletič, S. (2023). Sound and Waves. In M. F. Taşar & P. R. L. Heron (Eds.), *The International Handbook of Physics Education Research: Learning Physics* (pp. 1-1-1–34). AIP Publishing LLCMelville, New York. https://doi.org/10.1063/9780735425477_001

Foesel, A., & Gehring, I. (2025). Acoustics in the daily life of bats. *European Journal of Physics*, *46*(4), 045803. https://doi.org/10.1088/1361-6404/ade40f

Gardner, G. E. (2012). Using Biomimicry to Engage Students in a Design-Based Learning Activity. *The American Biology Teacher*, *74*(3), 182–184. https://doi.org/10.1525/abt.2012.74.3.10

Handayani, R. D., Lesmono, A. D., Prastowo, S. B., Supriadi, B., Dewi, N. M., Azis, K. R., & Thohir, M. A. (2024). Exploring Students' Engineering Design Thinking in The Renewable Energy Topic: A Case of Problem Identification and Developing Ideas and Plans. *Jurnal Pendidikan Fisika Indonesia*, *20*(2), 188–196. https://doi.org/10.15294/jpfi.v20i2.12781

Honey, M., Pearson, G., & Schweingruber, H. A. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. The National Academies Press.

Kaltakci, D., & Eryilmaz, A. (2011). Context-based questions: Optics in animal eyes. *Physics Education*, *46*(3), 323–327. https://doi.org/10.1088/0031-9120/46/3/012

Kaltakci-Gurel, D., & Gokce, E. (2025). Effects of biomimicry-enriched engineering design-based teaching on students' association with daily life, stem attitude, and biomimicry attitude in the sound and its properties unit. *Journal of Baltic Science Education*, *24*(5), 918–934. https://doi.org/10.33225/jbse/25.24.918

Kelley, T. R., Sung, E., Han, J., & Knowles, J. G. (2023). Impacting secondary students' STEM knowledge through collaborative STEM teacher partnerships. *International Journal of Technology and Design Education*, *33*(4), 1563–1584. https://doi.org/10.1007/s10798-022-09783-w

Korur, F., Efe, G., Erdogan, F., & Tunç, B. (2017). Effects of Toy Crane Design-Based Learning on Simple Machines. *International Journal of Science and Mathematics Education*, *15*(2), 251–271. https://doi.org/10.1007/s10763-015-9688-4

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

McComas, W. F., & Burgin, S. R. (2020). A Critique of "STEM" Education: Revolution-in-the-Making, Passing Fad, or Instructional Imperative? *Science & Education*, *29*(4), 805–829. https://doi.org/10.1007/s11191-020-00138-2

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook* (Fourth edition). SAGE

Mohd Shahali, E. H., Halim, L., Rasul, M. S., Osman, K., & Zulkifeli, M. A. (2016). STEM Learning through Engineering Design: Impact on Middle Secondary Students' Interest towards STEM. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(5). https://doi.org/10.12973/eurasia.2017.00667a

Next Generation Science Standarts [NGSS]. (2013). *Next Generation Science Standards: For States, By States*. https://www.nextgenscience.org/

Othmani, N. I., Mohd Yunos, M. Y., Ramlee, N., Abdul Hamid, N. H., Mohamed, S. A., & Yeo, L. B. (2022). Biomimicry Levels as Design Inspiration in Design. *International Journal of Academic Research in Business and Social Sciences*, *12*(8), Pages 1094-1107. https://doi.org/10.6007/IJARBSS/v12-i8/14679

Pauls, S. (2017). Biomimicry a “Natural Lesson” in STEAM. *STEAM*, *3*(1), 1–2. https://doi.org/10.5642/steam.20170301.33

Pilot, A., & Bulte, A. M. W. (2006). Why Do You “Need to Know”? Context-based education. *International Journal of Science Education*, *28*(9), 953–956. https://doi.org/10.1080/09500690600702462

Qureshi, S. (2022). How students engage in biomimicry. *Journal of Biological Education*, *56*(4), 450–464. https://doi.org/10.1080/00219266.2020.1841668

Roobeek, M. (2019). *Biomimicry in the Classroom*. https://biolearn.eu/assets/documents/dutch-manual/Research-Report-Matthijs-Roobeek-How-Biomimicry-can-be-integrated-in-the-Dutch-curriculum.pdf

Stevens, L., De Vries, M. M. J., Bos, M. M. J. W., & Kopnina, H. (2019). Biomimicry Design Education Essentials. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 459–468. https://doi.org/10.1017/dsi.2019.49

Stevens, L. L., Whitehead, C., & Singhal, A. (2022). Cultivating Cooperative Relationships: Identifying Learning Gaps When Teaching Students Systems Thinking Biomimicry. *Biomimetics*, *7*(4), 184. https://doi.org/10.3390/biomimetics7040184

Tuada, R. N., & Suparno, S. (2021). Increasing Student’s Hots Using Mobile Technology and Scaffolding Approach on Sound Wave Material. *Jurnal Pendidikan Fisika Indonesia*, *17*(2), 160–174. https://doi.org/10.15294/jpfi.v17i2.26949

Volstad, N. L., & Boks, C. (2012). On the use of Biomimicry as a Useful Tool for the Industrial Designer. *Sustainable Development*, *20*(3), 189–199. https://doi.org/10.1002/sd.1535

Zhang, L., Lin, Y., & Oon, P.-T. (2025). The implementation of engineering design-based STEM learning and its impact on primary students’ scientific creativity. *Research in Science & Technological Education*, *43*(2), 568–588. https://doi.org/10.1080/02635143.2024.2309907