DESIGNING A SOUND REDUCING WALL

Students explore engineering with a fun challenge.

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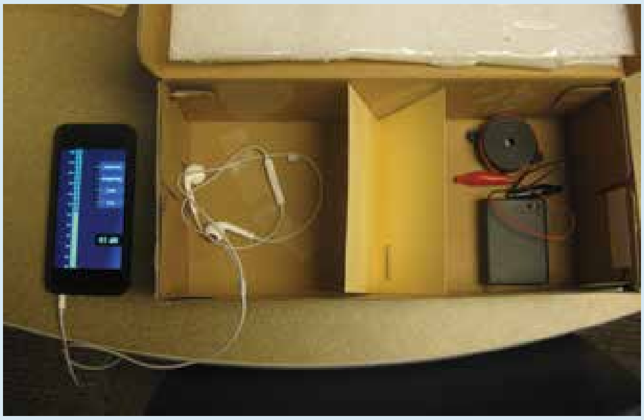
Many of the structures and environments that we encounter in our daily lives are designed to interact with sound waves in a very specific way. For example, the carpeted floors of a library or movie theater are designed to absorb sound waves and create a quiet environment, while the smooth tile floors of a gymnasium are designed to reflect sound waves and create a noisier environment. Acoustical engineers use their knowledge of sound to design quiet environments (e.g., classrooms and libraries) as well as to design environments that are supposed to be loud (e.g., concert halls and football stadiums). They also design sound barriers, such as the walls along busy roadways that decrease the traffic noise heard by people in neighboring houses.

FIGURE 1.

Image of the two-room testing model, composed of the "quiet" room (left) and the "loud" room (right) separated by an empty wall pocket.



The Science of Sound

When sound waves come in contact with different objects, portions of the waves are typically *reflected* and *absorbed*. For the reflected portion of a sound wave, the forward motion of the wave is changed by the object and the wave bounces back toward the source of the sound (e.g., an echo response) or in a different direction. Most objects also absorb energy from the sound wave, causing the sound level of the reflected wave to be reduced. The sound will appear to be quieter or possibly disappear entirely to a person listening nearby.

When energy from a sound wave is absorbed by an object, the absorbed energy causes the atoms in the object to rapidly vibrate and bump into neighboring atoms, allowing for the sound energy to propagate or travel through the object. Depending on what the object is made of, the energy will either travel through the object very quickly and efficiently with little absorption or it will travel slowly and inefficiently with most of the energy being absorbed by the object. For example, the sound generated by a person knocking on a wooden door will travel through the wood and can easily be heard by a person on the other side of the door. Very little sound energy is absorbed by the dense wood that is used to make the door. However, the sound generated by a person walking on a carpeted floor cannot easily travel through the porous material of the carpet. Instead, the sound energy is absorbed by the material so that, for example, a person walking on a carpeted second floor of a house cannot easily be heard by a person on the first floor.

To help students better understand sound in a fun and engaging way, we conducted an engineering design-based science learning activity that is appropriate for a one-hour time block in a third- or fourth-grade classroom. In this activity, student teams were challenged to design, construct, and test a sound-reducing wall created from common classroom materials. Before we began the activity, we described the basic properties of sound waves to the students, including the ability of sound waves to travel through the air from the sound source (e.g., alarm clock) to a nearby listener (e.g., sleeping person) and their ability to be reflected or absorbed by different materials (see Sidebar, "The Science of Sound"). This activity allowed students to explore the sound absorbing or reflecting properties of different types of materials, providing connections between science concepts and real-world experiences. It could be useful to perform this engineering design-based activity following an inquiry-based activity that explores the properties of sound in-depth, including the transmission of sound by waves and vibrations (Merwade et al. 2014). In the sound-reducing wall design activity, the participating students demonstrated the ability to articulate the key aspects of solving a problem using the design process and at the same time were excited about implementing, assessing, and communicating the results of their team effort. It is important to note that here, results are described from a grade 3 classroom, as historically the science of sound was a third-grade academic science standard in the state of Indiana. Additionally, there are opportunities to extend this activity through connections to the *Common Core State Standards* in mathematics, particularly with recording, graphing, and interpreting numerical data.

Lesson Overview

Due to space, time, and material constraints, the sound-reducing wall created by students was scaled to the size of a standard shoe box (see Figure 1). The sound-reducing wall divided the shoe box into two "rooms": a "loud" room in which a sound was generated with a kitchen timer or electric buzzer and a "quiet" room which contained a sound meter for measuring the amount of sound that passed through the wall. For the

TABLE 1.

Time breakdown for the 60-minute activity.

Stage	Time Allotted
Read/discuss the design brief	10 min.
Brainstorm and individual design	5–10 min.
Team design and discussion	5–10 min.
Gather materials and construct the design	10 min.
Testing of design (6 teams)	10 min.
Class discussion of results and individual reflection	10–15 min.

sound meter, an external microphone (an earbud cable with a microphone, packaged with most smartphones) was placed in the room and connected to a smartphone that had a sound meter app installed (e.g., dB Volume). For a well-designed sound-reducing wall, there was a significant reduction in the level of sound that was measured with the sound meter when the buzzer was on and the wall was in place, compared to the level of sound when the wall was removed.

Student teams each constructed a wall that fit into this two-room testing model using a folded section of a manila folder as a "pocket" (see Figure 1). The teacher created one testing box for this activity and provided each student team with an empty wall pocket and access to different fill materials. Prior to the activity, the teacher gathered a variety of building materials that exhibited different sound-absorbing or reflecting qualities. Suggested building materials for wall construction include:

- Construction paper
- Foam board
- Cotton balls
- Fabric
- Bubble wrap
- Plastic sheet

The building materials were cut by the teacher to fit within the pocket. An additional benefit of using the pocket and pre-cut materials to create the wall was that the students did not need to use scissors, tape, or glue to form their building materials into a solid wall; instead, the materials that were selected for the wall based on their team design were just placed or layered within the pocket. The building materials, pockets, and two-room testing model were also able to be reused in the future.

Engineering Design Challenge

Table 1 summarizes the stages and timing of the engineering design challenge. This activity relied on the *Science Learning Through Engineering Design* (SLED) model for engineering design (Capobianco, Nyquist, and Tyrie 2013). Within this model, students were grouped in teams of three or four and worked together to first identify the overall context of the design problem or challenge. This was accomplished by reading and discussing a design brief, which was a short paragraph written by a team of university faculty and practicing teachers to provide the context of the problem and the criteria that must be addressed in the engineering design. The following design brief was used for this activity:

> A group of students are starting a rock band. One of the students' parents will allow the band to practice in their house but only if a sound-reducing wall is installed in the student's bedroom. The parents hire the Silence Is Golden Company to design the sound-reducing wall. As one of the company's acoustic engineers, you and your team must design, build, and test a wall that reduces as much of the noise that escapes from the student's bedroom as possible. The wall should be no thicker than 4.5 cm.

TABLE 2.

Design brief discussion questions.

Problem	Need a wall to reduce sound of instruments
Goal	To design a sound-reducing wall
Client	Parents
User	Parents and students in the band
Criteria	Wall should reduce sound as much as possible
Con-straints	(1) Thickness of no more than 4.5 cm (2) Time (3) Building materials

FIGURE 2.

Image of a student's individual design sketches (left) and a team design sketch (right).

A student sketches an individual design.

After reading the design brief together as a class, the teacher helped students identify the problem, goal, client, user, criteria, and constraints, which were identified and written on the board and copied into the student's notebooks (see Table 2). The teacher then showed the two-room testing model, the wall pocket, and the available building materials to the students and described how the walls would be tested using the buzzer and sound meter. At this point, if the students are unfamiliar with the concept of "design" and the role of the design brief, sketching, building, and testing within the design process, additional time should be allotted to discuss the different aspects of the design brief listed in Table 2 (focusing on the goal, criteria, and constraints) and the brainstorming and sketching time that will follow.

Next, time was allotted for the students to individually brainstorm and sketch design ideas in their lab notebooks based upon the information provided and their relevant background knowledge. The students then shared their design ideas with the members of their team and mutually

TABLE 3.

Results from testing the teams' sound-reducing walls.

Test	Sound Level (decibels)
Baseline	86
Team 1	75
Team 2	82
Team 3	78

agreed upon a final "team design," which was then copied into the lab notebooks of all the team members. Before the teams were allowed to begin construction of their design, the teacher checked to see that each team member's lab notebook contained a sketch of the team design. Examples of students' sketches are shown in Figure 2 (p. 55). The students were told that a good sketch is neatly drawn, large and centered on the page, and includes arrows and clearly written labels.

When the teams were ready to begin building, one student from each team gathered the materials to be used in construction of the wall based on their final team design. The teams then built the wall together using their team design as a guide and ensuring that the thickness of the wall did not exceed 4.5 cm. Due to the pre-cut materials that were assembled by the teacher, construction of the teams' walls took a relatively short amount of time during the activity (only 10 minutes).

Prior to testing any student-designed walls, a sound level baseline was established. To do this, an empty wall pocket was placed into the two-room testing model, the buzzer was turned on, and the lid of the box was tightly shut. The value displayed on the sound meter was the baseline sound level, and this value was recorded on the chalkboard. Next, one-by-one, the teams tested their finished walls in the two-room testing model with help from the teacher in a similar fashion, by replacing the empty wall pocket with their team's wall. To make the testing process more interactive, a document camera was used to project the image of the smartphone sound meter on the screen, so that the students could participate in

Students prepare their walls with help from the teacher.

reading the measurement of the sound level. The value of the sound level for each wall was recorded on the chalkboard; sample data is shown in Table 3. The students copied these results into their lab notebooks. Students can also include a third column where they calculate the difference between the baseline sound level and the sound level with a team's wall; for example, for Team 1 the difference would be 11 decibels (86–75=11).

To encourage the students to consider how sound travels through the different materials, ask the students which materials were the most porous (or least dense) and how well these low-density materials worked to reduce the sound level in the quiet room.

Following testing, the teacher led a group discussion about the results. First, the teacher asked the teams with the highest and lowest sound levels in the quiet room to describe the materials that were used in the construction of their wall. These were listed on the board and the students were asked why these materials make good or poor sound reducers. To encourage the students to consider how sound travels through the different materials, ask the students which materials were the most porous (or least dense) and how well these low-density materials worked to reduce the sound level in the quiet room. Also, ask whether any of the materials seemed to be particularly good at reflecting the sound energy. In their notebooks, the students ranked the materials from the most to least effective at reducing the sound level by absorption or reflection of the sound. If time permits, the teams can redesign their walls, using their new knowledge of good and poor sound-reducing materials to create a more effective sound-reducing wall. At the end of the activity, time was allotted for "self-reflection," in which the students copied and provided answers to the following five questions in their notebooks: (1) What did I do? (2) What worked well? (3) What didn't work well? (4) What would I change? and (5) What did I learn?

When this activity was implemented in the third-grade class, the students understood and were able to articulate the need, goal, client, user, criteria, and constraints after hearing the design brief. The students became very engaged in the design and testing process. When measuring each team's wall, the entire class was captivated and glued to the video screen to see the sound meter and cheered for each other when a team's wall did well. Making a list of values for each team provided friendly competition. Even teams whose walls did not reduce the sound as much as other teams were happy to share their design, talk about why they chose the materials they did, and discuss how they thought they could improve their design.

The teacher helps a student load their wall into the model.

Pre-cut materials were used for the construction of the wall.

When discussing as a group why they thought each material would or would not work well in reducing the sound levels in the quiet room, students frequently exclaimed that they believed "thicker walls would work better" at reducing the sound levels and that "since cotton balls are the thickest [material], they will work the best." These predictions are understandable based on the students' past experiences—e.g., putting a pillow over your head during a thunderstorm works better at blocking out the loud thunder than a thin bed sheet. Most teams attempted to construct the thickest wall possible, which even caused some of the students to abandon their team designs. For example, instead of layers of foam board, the students chose to construct the wall from layers of cotton balls, which were thicker.

But the students quickly discovered that cotton balls did not do the best job of reducing the sound. Instead, they directly observed that thinner walls made of foam board and plastic sheet were the most effective at reducing the sound level in the quiet room compared to thicker walls made from fabric or cotton balls. This is because, for effective sound reduction, the sound waves can either be reflected or absorbed. Many soft, porous materials (like cotton balls and fabric) absorb sound but do not reflect, whereas hard, flat materials (like plastic sheet) reflect well but do not absorb much sound. Foam board is an example of a material that both reflects sound (off of its flat, stiff surface) as well as absorbs sound (within its porous foam core). In this situation, the teacher could lead a discussion on how thicker walls may not always be better for sound reduction, and instead, the type of material that the wall is composed of matters more. If time allows, the teams could create a new team design for a sound-reducing wall based on the outcomes from the first round of testing and the post-testing discussion. This will allow the students to directly apply what they learned from the design activity and will also assess their overall level of understanding of how sound travels and interacts with different materials.

Assessment

The teacher performed informal assessments throughout the design process while walking around the room to observe the students' design notebooks, listened to team discussions, and questioned design plans in relation to science concepts. The teacher reviewed student notebooks for design brief details, individual design sketches, and team design sketches. The teacher provided a separate rubric for students to self-check their engineering design notebook (see NSTA Connection). The teacher then used the rubric to assess the engineering design notebook (see NSTA Connection). The teacher assessed the students' notebooks for the design brief information, individual designs, team designs, and student self-reflections. The teacher also administered a formal assessment after the design task in order to assess students' understanding of the science concept as well as the engineering design process. This assessment could be performed as a pretest and posttest (see NSTA Connection). Additionally, the students' understanding could be assessed from having the students create a sketch or fully sketch and construct a redesigned wall, based upon their observations from the outcomes of the activity. Students whose redesigned walls are more effective at reducing the sound level in the quiet room than their initial walls would be categorized as having a good understanding of the properties of sound. For a simple sketch (if there is not time for a full redesign activity), students who included a mix of materials within their sketched walls that have both good sound absorption (cotton balls) and sound reflection (plastic sheet, foam board) abilities would be categorized as having a good understanding of the properties of sound.

Overall, this science activity exposes elementary students to the engineering design process of brainstorming, planning, building, and testing while simultaneously demonstrating how sound waves travel and interact with different types of materials. This fun, hands-on activity allows the students to become acoustic engineers for the afternoon, hired by a client to design and build a sound-reducing wall with certain criteria and constraints. Student creativity is encouraged by the wide selection of building materials to choose from for their wall designs. At the same time, the actual construction process is simplified by using pre-cut materials provided by the teacher and a uniform testing model, allowing for all students to fully participate in the building and testing process. Working in small groups also increases the students' confidence and comfort with sharing ideas and combining separate ideas together to lead to improved designs. ■

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Acknowledgments

This project was supported by the National Science Foundation, Award # 0962840. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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NSTA Connection

Visit *www.nsta.org/SC1509* for the assessment and answer key, the rubric, and additional resources.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

3-5-ETS1 Engineering Design

www.nextgenscience.org/3-5ets1-engineering-design

The materials/lessons/activities outlined in this article are just one step toward reaching the performance expectations listed below. Additional supporting materials/lessons/activities will be required.

Performance Expectations	Connections to Classroom Activity
3-5-ETS1-1 Define a simple design problem reflecting a need or a want that includes specific criteria for success and constraints on materials, time, and cost. 3-5-ETS1-3 Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.	Students analyzed the design brief to determine the problem, goal, client, user, criteria, materials, and constraints. Students constructed, measured, and tested sound-reducing walls; recorded and analyzed sound level data; and redesigned their walls.
Science and Engineering Practices	
Asking Questions and Defining Problems Planning and Carrying Out Investigations Developing and Using Models Constructing Explanations and Designing Solutions	Students analyzed the design brief, created individual sketches of their ideas, chose a model, and constructed and tested it. Quantitative results were collected and analyzed as a group. Students determined which materials were the best based on their criteria.
Disciplinary Core Ideas	
ETS1.A: Defining and Delimiting Engineering Problems • Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.	After testing and class data analysis, the teams were given the option to redesign their wall. Following testing, the teacher led a discussion about all the results from the teams' walls and the materials that were the most and least effective at sound reduction were identified.
ETS1.B: Developing Possible Solutions • At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.	The students' individual design sketches were discussed within their teams. Teams created a final team sketch, constructed and tested the model, and described their design to the class, including a discussion of why they think it worked (or didn't work).
PS3.A: Definitions of Energy • Energy can be moved from place to place by moving objects or through sound, light, or electric currents.	Students directly observed the results of the transfer of sound from one space to another through different materials used to reduce sound.
Crosscutting Concept	
Influence of Engineering, Technology, and Science on Society and the Natural World	Students improved existing technology to reduce the sound level in the quiet room.