By Deepika Menon and Deanna Lankford

Making Sense of Sound

Fourth graders use physical and technological models to illustrate and explain the nature and characteristics of sound.

From the earliest days of their lives, children are exposed to all kinds of sound, from soft, comforting voices to the frightening rumble of thunder. Consequently, children develop their own naïve explanations largely based upon their experiences with phenomena encountered every day (Driver et al. 1994). When new information does not support existing conceptions, explanations are refashioned to agree with prior experiences, often resulting in misconceptions (Wesson 2001). Science education literature identifies multiple misconceptions related to sound commonly held by elementary students, including: Sound can only travel through air and not through solids and liquids; sound can travel through a vacuum, such as space; sound can be produced without using any materials; and hitting an object harder changes the pitch of the sound produced (Stepans 2006). Inquiry-based activities challenge students to question their own conceptions and build new conceptual understanding in light of new evidence. To that end, we designed a 5E (Bybee 1997) inquiry-based lesson to engage fourth graders in an exploration of sound, focusing specifically on sound as a mechanical wave.

Performance expectations from the *Next Generation Science Standards* (*NGSS*) specifically indicate that students should be engaged in scientific practices such as modeling to support learning. Drawing upon *NGSS* performance expectation 4-PS4-1, we used physical and technological models to (1) demonstrate that sound is a form of energy associated with vibration of matter and can cause other objects to move and (2) describe sound wave patterns in terms of amplitude and wavelength (NGSS Lead States 2013). The physical and technological models described could be further extended to illustrate energy transfer through sound (4-PS3-2).

Engage: Creating the "Hook"

We began by introducing a concept cartoon probe (Figure 1) to reveal students' preconceptions about sound and stimulate interest in learning about sound. Concept cartoons engage young learners through visual characters with whom it is easy to connect (Keeley 2013). The concept cartoon was created at *MakeBeliefsComix.com*, a free online resource available for creating concept cartoons. In the cartoon, two characters are discussing sound, and we asked students to choose the character they agree with and justify their choice. We asked questions such as: "Why do you think Lily is right?" "Can you give an example to support your idea?" The discussion revealed that students had varied ideas related to sound as they explained their choices. For instance, one student agreed with Alex and mentioned phone movement (referring to vibrations) when it rings and another student mentioned "jiggles" on the car dashboard when loud music is played. We found that few students agreed with both Lily's and Alex's ideas; however, they were unable to explain their thinking. We drew a data table on the interactive whiteboard showing the number of students who chose Lily, Alex, neither, or both. Having this data was important as we wanted to revisit this prompt after students investigated sound. After the discussion, we asked students how they would decide on the correct response. Some students suggested that we should test our ideas. We emphasized that experiments allow us to test our ideas, observe what happens, and then draw from the evidence to explain our findings. With that notion, the class was divided into teams of four. Each team member had a responsibility such as materials manager, data recorder, task manager, and time manager. Our contention was that assigning roles would reduce confusion and provide a specific task for each student.

Explorations and Explanations

We designed two activities to help students understand that (1) sound is produced by vibration and (2) sound can cause other objects to vibrate. Before distributing the materials, we established safety expectations as a class. For example, a tuning fork should be tapped only on the mallet provided and should be held firmly by the handle when striking the prongs. Students were further instructed not to play with or throw rubber mallets, that rice grains and sugar crystals are not to be eaten, and that paper towels should be put underneath the plastic cups filled with water to absorb any spill over. Students were also reminded to take turns to perform each experiment and gently hand over the tuning fork to the next student. For the first activity, we provided two tuning forks of different frequencies and a mallet to each group. See NSTA Connection, Explor-

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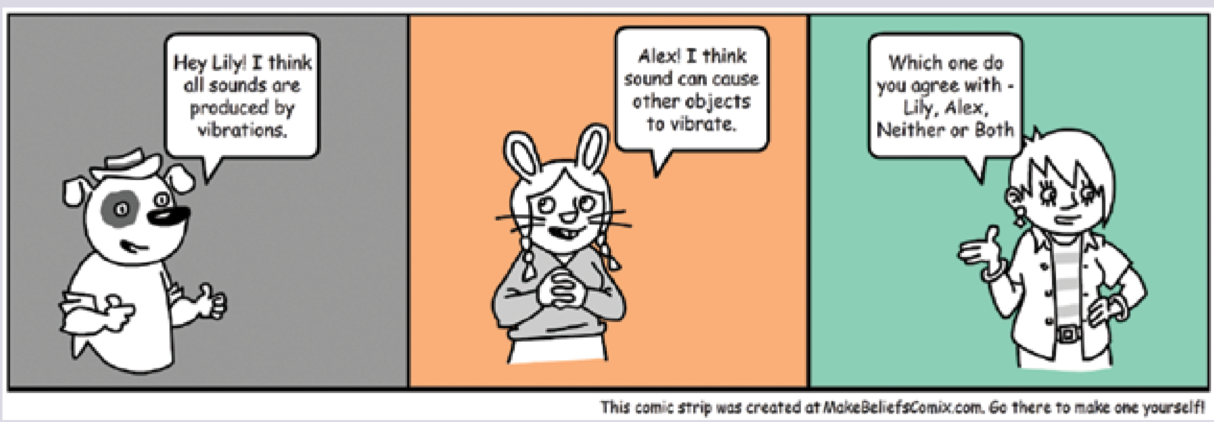
FIGURE 1.

Concept cartoon.



PHOTOS COURTESY OF THE AUTHOR

Students use tuning forks to explore sound.

ing Sound as a Mechanical Wave, for teacher notes, including guidelines for setting up the activity and answer key for the student activity sheet. The students were asked to strike each tuning fork one at a time and bring it close to their ear. Each student received an activity sheet and was asked to respond to the questions posed (see NSTA Connection for a copy of the student activity sheet). The first question asked was, "How do tuning forks create sound?" Students began to notice that the vibrating tuning forks produced sound. Some students also noticed that tuning forks with different prong length created different sounds. We encouraged students to think about how the sound compared with the length of the tuning fork prongs. Once the groups completed the activity, we asked each group to write their "summary statement" on the whiteboards. All groups noticed that the length of the tuning fork was related to pitch (sharpness) of the sound and that the longer the length of the tuning fork, the lower the pitch.

In the next activity, we asked students to place rice grains or sugar crystals on the top of a cup covered with plastic wrap. The students were asked to strike the tuning fork on a mallet and bring it closer to the cup. Some of the guiding questions asked were: "Describe what happened to rice grains or sugar." "What caused the rice grains or sugar to move?" Students soon realized that as they brought the vibrating tuning fork near the sugar crystals, the sugar crystals moved. Note that sugar or salt crystals bounce dramatically when the tuning fork was held in close proximity. Rice grains are too large and weigh the plastic wrap down, reducing vibrations. The groups were asked to write their summary statement(s) for this activity on the whiteboard. For instance, one group noted that "sound vibrations can move other objects just as sugar crystals." Next, we asked students to explain what they observed and justify their statements with evidence-based explanations. All groups came to the conclusion that sound can cause objects to vibrate or move, as in the case of sugar crystals. At this stage, it was important to revisit the cartoon prompt as a formative assessment to check students' understanding. Now all of the students agreed with both Lily and Alex (Figure 1).

Elaborate: Characteristics of a Sound Wave

Once students understood the concept of sound vibrations, the next step was to help students understand the nature and characteristics of a sound wave. This activity required students to work on an iPad app called *Twisted*

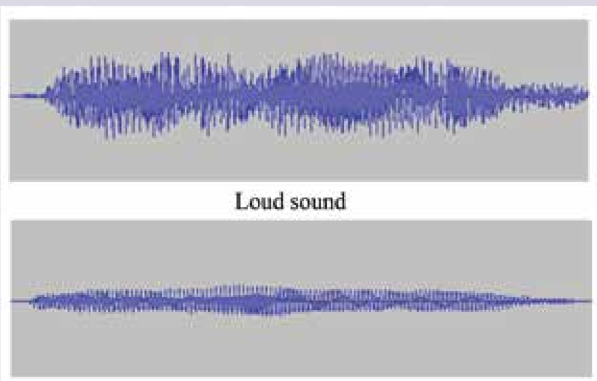
During student discussions, it is important to point out that student diagrams, whiteboard displays, and the app are simplified ways to understand how sound waves work, but these models are limited and only provide a two-dimensional view of a sound wave.

Wave Recorder (see NSTA Connection, Exploring Sound with Technology, for teacher notes and student activity sheet). Teachers may need to preload the app on the iPad and also regroup students depending on its availability. Alternatively, iPhones could also be used depending on the cell phone policy of the school. Teachers may want to carry out the activity as a whole-class activity or as a separate station. Students were asked to record their voices while making soft, loud, high, or low sounds. We asked, "What differences do you notice when you speak softly versus when you speak loudly?" Students were very excited to see the effects of sound vibrations as they took turns recording their voices and also realized that sound vibrations have a wavelike structure (see Figure 2). A "note for teachers" (beyond the level of student assessment) is that the sound waves are three-dimensional longitudinal waves generated by back-and-forth movement of particles around their equilibrium position creating high and low pressure regions. The model generated by the app is a two-dimensional waveform representing characteristics of sound waves such as amplitude and frequency. During student discussions, it is important to point out that student diagrams, whiteboard displays, and the app are simplified ways to understand how sound waves work, but these models are limited and only provide a two-dimensional view of a sound wave.

We asked students to draw pictures of their observations of louder versus softer sound in their journals. The activity is well-aligned with *NGSS* performance expectation PS4-1: Develop a model of waves to describe patterns in terms of amplitude and wavelength. We realized the importance of student representations for revealing their understanding of wave structures. When asked to share their drawings, students explained that the wave-nature of sound varied with low versus high-pitched sounds. Students also realized that with the higher sounds, waves are closer together, whereas with low sounds, the waves are farther apart. At this point, we introduced the scientific terminology for loudness of the sound as *amplitude* and the pitch of the sound as *frequency*. Once students became familiar with the scientific vocabulary, they were asked to note the differences between the amplitude of loud versus soft sound. We explained that sounds with greater amplitude are louder and more energy is transferred by the wave. We further challenged students to compare the pitch of the two tuning forks of different lengths. Students noted that the longer tuning fork produced a lower pitch than the shorter one.

FIGURE 2.

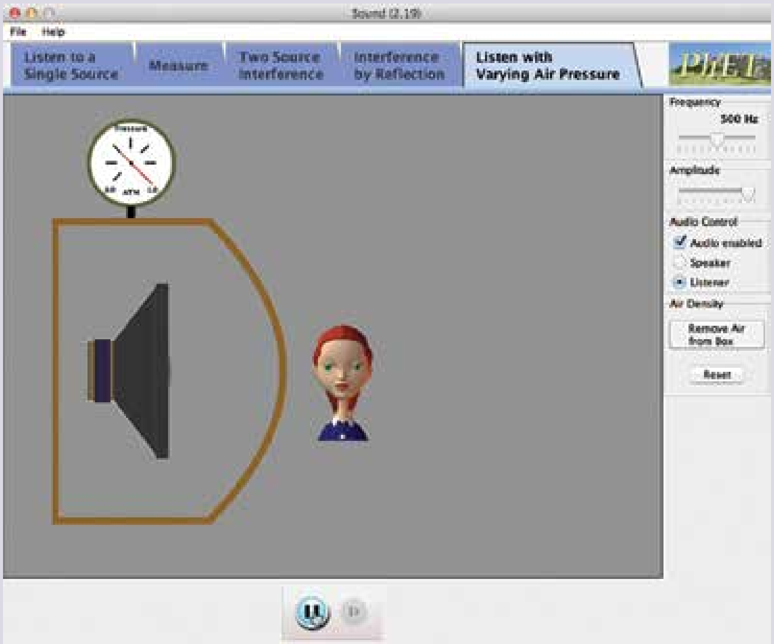
Two-dimensional view of the waveform generated by Twisted Wave recorder.



Bringing the tuning fork close to the cup caused movement of rice grains atop plastic wrap.

FIGURE 3.

PhET simulation to understand that sound waves do not travel in a vacuum.



Extend: Sound Needs a Medium to Travel

To establish the concept of sound as a mechanical wave, we designed activities to illustrate that sound requires a medium to propagate. At three stations, students were asked to make and test predictions. At Station 1, students investigated sound waves traveling through liquids. Students were provided with a cup of water and then asked to touch the prongs of the vibrating tuning fork to the surface of the water. Students were thrilled to see ripples when the vibrating tuning fork touched the water surface and were able to visualize that sound can cause water to vibrate. Station 2 introduced the concept that sound vibrations can travel through solids. This was demonstrated as students spoke to one another using tin-can or plastic-cup telephones (see NSTA Connection, Exploring Sound: Plastic Cup Telephones, for teacher notes and student activity sheet). Students were encouraged to investigate how sound travels along the telephone. This station can be designed to challenge students to experiment with the effectiveness of plastic cup or tin-can telephones or explore the effectiveness of string, nylon fishing line, or yarn as the connecting material. Students were amazed to hear their voices as the sound waves traveled from cup to cup. During our discussion, students revealed an understanding that sound vibrations propagate through a medium.

At Station 3, we assessed students' understanding of sound as a mechanical wave that requires a medium to propagate. We discussed their ideas first, before using iPads. We first asked students to predict: "Can sound waves travel through space [a vacuum] where there is no medium?" We asked students to discuss their ideas within small groups. Then, we incorporated the PhET simulation on sound (see NSTA Connection, Exploring Sound with Technology, for teacher notes on using PhET simulations and student activity sheet). Virtual simulations available from PhET (*http://phet.colorado.edu/en/simulation/sound*) use technology to engage students with sound as they manipulate the frequency and amplitude of sound waves. We downloaded the PhET simulation on an iPad for students to be able to start investigating right away (Figure 3). This activity may require teachers to guide students through various controls such as enabling audio, clicking on the listener, and setting frequency and amplitude ranges. Once our students

Students try out a plastic-cup phone.

were comfortable with the simulation, we asked, "What do you think will happen if we remove air from the box?" This helps determine student understanding of the concept of sound as a mechanical wave. Then we asked students to remove air from the box in the simulation, and they realized that there were no sound waves reaching the listener when all the air was removed.

Evaluation: Demonstrating Learning

This lesson is structured so that formative assessments run seamlessly throughout. You could extend this lesson for students to demonstrate their understanding of sound in various fun ways, such as creating their own toys or various instruments that make sound. For our summative evaluation, we provided two scenarios (Figure 4). The first cartoon scenario was structured to assess students' understanding of sound as a mechanical wave transferring energy from one medium (air) to another medium (water). The second cartoon scenario prompted students to determine if sound would propagate in a vacuum. For instance, would we hear an explosion in outer space? From the various experiences with physical and technological models aimed for understanding the nature and characteristics of sound, the students developed a deeper understanding of sound as a mechanical wave. More important, the lesson was able to address common misconceptions, which challenged students to construct more appropriate scientific explanations from evidence-based results. ■

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FIGURE 4.

Summative assessment scenarios.

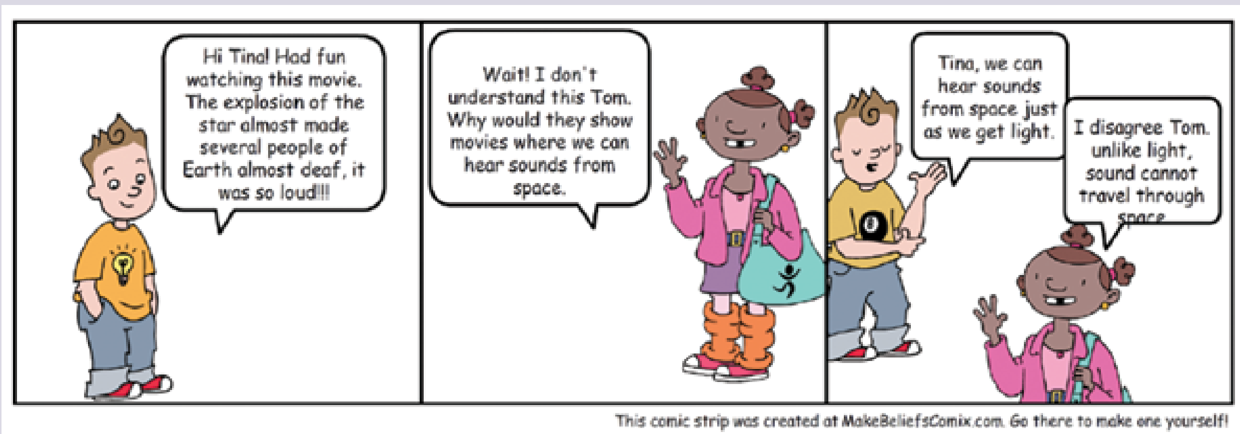
Scenario 1: Sharon's favorite hobby is underwater swimming and diving. She wonders whether she would be able to hear her friends calling from outside the pool when she is underwater. What do you think?

Student 1: I think she should be able to hear when she is underwater. Sound vibrations can travel through different mediums.

Student 2: I think she would not be able to hear. Sound vibrations need air to travel to human ear.

Which student do you agree with if any? Provide support for your answer.

Scenario 2: Cartoon prompt



Do you agree with Tina or Tom, both or neither? Please explain your choice.

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NSTA Connection

Download teacher materials and student handouts at *www.nsta.org/SC1612*.

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

4-PS4 Waves and Their Applications in Technologies for Information Transfer

www.nextgenerationscience.org/4ps4-waves-applications-technologies-information-transfer

The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

Performance Expectation	**Connections to Classroom Activity** *Students:*
4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move.	• develop models (drawings) to explain the wave-nature of sound—amplitude and frequency after hands-on activities and interactive technological tools. • develop evidence-based explanations to illustrate how sound is produced by vibrations and that vibrations can cause objects to move (rice grains).
Science and Engineering Practices	
Developing and Using Models	• analyze two-dimensional wave pattern produced by Twisted Wave app to explain the characteristics of a wave. • construct drawings/pictures to illustrate and explain wave-nature of sound.
Disciplinary Core Idea	
PS4.A: Wave Properties Waves, which are regular patterns of motion, can be made in water by disturbing the surface. Waves of the same type can differ in amplitude [height of the wave] and wavelength [spacing between wave peaks]	• observe changes in the surface of the water when touched by a vibrating tuning fork. • compare wave patterns in terms of amplitude and frequency by varying their voices when they speak through the app.
Crosscutting Concept	
Patterns	• use software to manipulate and classify sound in terms of pitch and loudness by observing the change in patterns of the sound waves.