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 SE (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.

Hey Lily! I think all sounds are produced by vibrations.

Alex! I think sound can cause other objects to vibrate.

Which one do you agree with - Lily, Alex, Neither or Both

This comic strip was created at MakeBeliefsComix.com. Go there to make one yourself!
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.](image)

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

![Cartoon Image](image-url)

Do you agree with Tina or Tom, both or neither? Please explain your choice.
Connecting to the **Next Generation Science Standards (NGSS Lead States 2013):**

<table>
<thead>
<tr>
<th>Performance Expectation</th>
<th>Connections to Classroom Activity</th>
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</table>
| 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.
# 1-Exploring Sound as a Mechanical Wave

**Activity Overview**
The goal of this activity is to investigate sound as a mechanical wave. Sound waves are mechanical waves that require a medium to be conducted. We typically hear because air molecules vibrate, collide with one another, and, in this way, conduct the sound waves to our ears.

**Materials**
- Tuning forks
- Mallets
- Plastic cup covered with plastic wrap
- Water in a plastic cup
- Sugar (or salt) or rice grains

**Guiding Question**
How can you make sound visible using tuning forks and other materials like sugar crystals or rice grains on a plastic wrap or water in a plastic cup?

### Exploring Sound Using a Physical Model

**Step 1: Tuning Forks**
- Provide students two tuning forks with different frequencies. The tuning forks will vary in prong length.
- Instruct students to hold the tuning fork near their ear.
  - Questions:
    - Is the tuning fork making a sound?
    - Is the tuning fork vibrating?
- Next, tell students to tap the tuning fork on the rubber mallet.
- Again instruct students to hold the tuning fork near their ear.
  - Questions:
    - Is the tuning fork making a sound?
    - Is the tuning fork vibrating?
- There are several different tuning forks to choose from. Students should select a different tuning fork, tap the fork on the mallet and listen carefully to the sound produced.
  - Questions:
    - Does the fork produce the same sound as the tuning fork tapped earlier? How are the tuning forks different from one another?

**Step 2: Using sugar crystals to explore sound vibrations**
- Instruct students to use the cup covered in plastic wrap for step 2.
- Place a pinch of sugar crystals on the surface of the plastic wrap.
- Next, tap the tuning fork on the mallet and hold the vibrating fork as close to the surface of the plastic wrap and sugar crystals as possible.
  - Questions:
    - What happened to the sugar when the vibrating tuning fork was held close to the plastic wrap?

A physicist will tell you that sound waves are mechanical waves. Can you identify any evidence from this investigation to support that claim?
| Can sound propagate in water? | **Step 3: Exploring Sound with Water**  
- Students should select a tuning fork, mallet, and a cup of water.  
- Instruct students to tap the tuning fork on the mallet and hold the fork near their ear. Listen to the sound created.  
- **Can you make sound visible?** Instruct students to move the tuning fork so that it is near the surface of the water. **It is important to note that when you strike a tuning fork on a mallet, the prongs of the tuning forks are moving back and forth rapidly. This vibration causes the air around the prongs of the tuning fork to vibrate as well. Vibrations of particles in the air are not visible, we cannot see sound. However, we can see the effects of the vibrating tuning fork when the fork is held close to water and ripples form on the surface of the water.**  
  - Question:  
    - Can you see ripples in the water when the tuning fork is held close to the surface? Why do you think ripples form on the surface of the water?  
- Next, tap the tuning fork on the mallet and touch the tuning fork to the surface of the water.  
  - Questions:  
    - What happens when you touch the vibrating tuning fork to the surface of the water?  
    - How can you tell if the tuning fork is vibrating? |
| --- | --- |
| **Something to think about** | **Statement:** Sound is a mechanical wave.  
  - Ask students if they can find evidence from their observations and experiences with the activities described to support that statement.  
  - Ask students to think about the three sound related activities completed during this investigation and draw conclusions from it. |
| **Linking to the Standards** | Next Generation Science Standards:  
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.  
**Disciplinary Core Ideas:**  
- Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; there is no net motion in the direction of the wave except when the water meets a beach.  
**Science and Engineering Practices:**  
- Develop a model using an analogy, example, or abstract representation to describe a scientific principle.  
**Crosscutting Concepts:**  
- Similarities and differences in patterns can be used to sort, classify, and analyze simple rates of change for natural phenomena. |
<table>
<thead>
<tr>
<th>Assessment</th>
<th>Formative assessment is suggested:</th>
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<tr>
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<td>• Use the questions suggested at each step as a means to assess students’ understanding.</td>
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<td>o Challenge students collaborating in teams to analyze their observations and interpret their data to develop supporting evidence to describe sound as a mechanical wave.</td>
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<td>• The questions listed on the student pages can also be used as a means of assessment.</td>
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Sound Science: **Exploring Sound as a Mechanical Wave** [Teacher page: Answer sheet]

Name: ________________________________

**Step 1: Testing Tuning Forks**

1. Do all tuning forks make the same sound?  No   Explain your answer in the space below:

   A tuning fork is an acoustic resonator which will vibrate at a specific pitch when tapped on a hard surface [rubber mallet]. The tuning forks are different in several ways (a) the prongs of the forks are different lengths and (b) the tuning forks produce different frequencies (pitch) when tapped making high or a low pitched sound. The tuning forks could also be different in colors and may weigh differently. This may be an indication that the tuning forks could be made up of different metals (alloys).

2. How do you think the tuning fork make a sound when you tapped it on a mallet?

   The prongs of the tuning fork were vibrating after being tapped on the mallet. The vibration is responsible for the sound the tuning fork makes when tapped.

3. Could you stop the sound made by the tuning fork?  Yes   How did you do that?

   If the student holds the prongs of the vibrating tuning fork, the vibrations will stop.

**Step 2: Making Sound Visible**

1. What happens to the grains of sugar crystals students placed on the plastic wrap covering the mouth of the cup?

   The sugar crystals also vibrate. Once again, the energy in the vibrating prongs is transferred to the plastic wrap. As the plastic wrap vibrates, the sugar crystals appear to jump. This is additional evidence that sound is a mechanical wave which can actually cause other objects or materials to vibrate. Students were able to observe this phenomenon in Steps 2 and 3.

**Step 3: Making Sound Visible**

1. How does the water change when the vibrating tuning fork is held close to the surface of the water?

   It is important to remember that the tuning fork produce vibrations after being tapped on the mallet. The vibrating prongs cause vibrations in the air and these vibrations are transferred through air molecules which we are able to hear. When the vibrating fork is held close to the surface of water, the water’s surface also vibrates and ripples appear. If the student touches the vibrating prongs to the water, the water splashes out of the cup. The energy is transferred from the vibrating prongs to the water in the cup.
Sound Science: Exploring Sound as a Mechanical Wave

Name: ________________________________________________

Step 1: Testing Tuning Forks

1. Do all tuning forks make the same sound? ____ ____ Explain your answer in the space below:

2. How do you think the tuning fork make a sound when you tapped it on a mallet?

3. Could you stop the sound made by the tuning fork? ______ How did you do that?

Step 2: Exploring Sound with Sugar Crystals

4. What happens to the grains of sugar placed on the plastic wrap covering the mouth of the cup?

Step 3: Exploring Sound with Water

1. How does the water change when the vibrating tuning fork is held close to the surface of the water?
Sample Checklists used for assessment (Heroman et al. 2010).

### Demonstrating Positive Approaches to Learning – Attends & Engages

<table>
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<tr>
<th></th>
<th>Pays attention to sights and sounds</th>
<th>Sustains interest in working on task with adult suggestions and productive questioning</th>
<th>Sustains interest on task, can ignore most distractions</th>
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<tbody>
<tr>
<td>Student A</td>
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<td>Student C</td>
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### Demonstrating Positive Approaches to Learning – Solves Problems

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<thead>
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<th>Has a reaction to a problem</th>
<th>Observes and imitates how others solve problems</th>
<th>Solves problems without having to try every possibility</th>
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### Demonstrating Positive Approaches to Learning – Shows curiosity and Motivation

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<th></th>
<th>Uses senses to explore</th>
<th>Explores and investigates ways to make something happen</th>
<th>Shows eagerness to learn about a variety of topics and ideas</th>
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Activity Overview
The goal of this activity is to investigate sound as a mechanical wave which requires a medium to be conducted. Students will use kite string to conduct sound from one plastic cup to another as we explore sound as a mechanical wave with plastic cup telephones. We have established sound as a mechanical wave with tuning forks in other activities. This activity relies upon string as the medium for conducting sound as one student speaks into the cup and the other listens.

Materials
Plastic cups
Kite string [15 ft. per plastic cup telephones]
Paper clips

Guiding Question
Can string connecting two plastic cups serve as the medium for conducting sound from one cup to the other?

Exploring Sound

Can string conduct sound waves when students speak into plastic cups connected by kite string?

Station 4: Plastic Cup Telephones
- Poke a small hole in the bottom of two plastic cups.
- Pull each end of a 15 ft. length of string through the hole in the bottom of the cup.
- Attach each end of the string to a paper clip so that the two cups are connected by the string secured to each cup with a paper clip.
- Ask students: What if you did not have a cell phone or even a land-line telephone. Could you design a simple telephone from cups and string?
  - Note that students are likely to respond by saying texting the other person would be a solution. Respond by indicating that there are no smart phones.
  - Could students use two cups connected by a length of string to relay a spoken message to one another? Would the string conduct the sound waves from the speaker to the other person holding the cup over his/her ear?
- Pair students and ask students if they think the sound of their voice will be conducted by the string so that their partner can hear what they are saying.
  - Instruct students to stand far enough apart from one another so that the string is stretched between the two cups.
  - Instruct the students to move closer together so that the string is slack or no longer stretched tight between the two cups.
  - Can the students still hear one another? Why? Why not?
- Next, when one person is speaking, ask a third student to hold the string with his/her hand. Ask the student listening to the message if he/she can still hear when someone is holding the string.
  - Can you still hear the other person when someone is holding the string? Explain your answer.
### Something to think about
- Statement: Sound is a mechanical wave.
  - The sound of the human voice is created by the vibration of our vocal cords when we speak. During this activity, the vibration of vocal cords causes the air inside the cup to vibrate. The vibrating air caused the cup to vibrate and eventually the vibration is conducted to the string connecting the two cups. Sound waves generated by one student are conducted to the second cup by the string to become a detectable sound.
  - In this activity, the cup, air, and the kite string were the media conducting the vibrations created by the vocal cords of the student speaking. When the string was stretched between the two cups, the vibrations were easily conducted by the string from one cup to the other. However, when the string was slack or sagged between the cups, the vibrations were less likely to reach the second cup.
  - When the string was held by another student, the vibrations could no longer travel along the string from one cup to the other. The string ceased to vibrate at the point where it was held.

### Linking to the Standards
Next Generation Science Standards:

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.

Disciplinary Core Ideas:
- Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; there is no net motion in the direction of the wave except when the water meets a beach.

Science and Engineering Practices:
- Develop a model using an analogy, example, or abstract representation to describe a scientific principle.

Crosstcutting Concepts:
- Similarities and differences in patterns can be used to sort, classify, and analyze simple rates of change for natural phenomena.

### Assessment
Formative assessment is suggested:
- Use the questions suggested at each step as a means to assess students’ understanding.
  - Challenge students collaborating in teams to analyze their observations and interpret their data to develop supporting evidence to describe sound as a mechanical wave.
- The questions listed on the student pages can also be used as a means of assessment.
Plastic Cup Telephones:

1. During this activity you and your partner used two plastic cups connected by a string a very basic telephone. You and your partner should each hold one of two plastic cups connected by a length of kite string. Stand far enough apart [approximately 15 ft.] so that the string is stretched between the two cups. Next, take turns speaking and listening to one another.
   a. When your partner spoke into his/her cup, could you hear what was being said?

Yes, your partner’s voice could be heard because the vibration resulting from his voice [created by vibrating vocal cords] was conducted by the string from one phone to the other. Sound travels very fast [approximately 1,126 ft/sec] so you were not likely to see the string vibrate or notice a delay in the time it took for the sound of your partner’s voice to reach your cup.

b. Do you think the string conducted the vibrations created by your partner as he/she spoke into the cup? **Yes** What evidence from your experience with sound could you use to explain your observations during this investigation?

Sound is a mechanical wave which means that sound can actually cause other things or materials to vibrate. For instance, the sound created by a vibrating tuning fork can cause ripples in the surface of water. Sugar crystals placed on plastic wrap over a plastic cup will bounce when a vibrating tuning fork is held close to the mouth of the cup.

In this investigation, the string functions to conduct the vibration from one cup to another when a student speaks into one of the cups. When the string is slack or no longer stretched tight between the two cups, the vibrations are not conducted as efficiently and it is no longer possible to hear your partner speak.

When the string is held by a third person, the vibrations can no longer move freely over the string. Just as when you grasp the prongs of a vibrating tuning fork, the vibrations cease, the same outcome results when the string is held by a third person.
Plastic Cup Telephones:

1. During this activity you and your partner used two plastic cups connected by a string a very basic telephone. You and your partner should each hold one of two plastic cups connected by a length of kite string. Stand far enough apart [approximately 15 ft.] so that the string is stretched between the two cups. Next, take turns speaking and listening to one another.
   a. When your partner spoke into his/her cup, could you hear what was being said?

b. Do you think the string conducted the vibrations created by your partner as he/she spoke into the cup? ____ What evidence from your experience with sound could you use to explain your observations during this investigation?
### Activity Overview
The goal of this activity is to provide students with a culminating experience with sound. The virtual simulation PhET Sound is found at the following URL [https://phet.colorado.edu/en/simulation/sound](https://phet.colorado.edu/en/simulation/sound) and the Twisted Wave Recorder app will be used for these investigations.

### PhET
Using PhET simulation, students will have opportunities to understand characteristics of a sound wave by manipulating frequency, amplitude, and air pressure. The images of sound waves the students will observe are representations of sound waves. PhET is an animated simulation modeling sound waves, although it does not show 3-dimensional model of a sound wave.

### Materials
- Laptops
- Tablets
- Slinky

URL: [https://phet.colorado.edu/en/simulation/sound](https://phet.colorado.edu/en/simulation/sound)

### Guiding Questions for PhET Simulation
We will use the PhET simulation to explore sound as a mechanical wave. There are three questions we want to answer:
- How does sound travel through a medium such as air?
- Can sound travel in a vacuum like outer space where there is no air?

### Exploring Sound with PhET
- **Since a sound wave is a disturbance that is transported through a medium [air] via a particle to particle interaction, sound is a mechanical wave requiring a medium.**

- **Exploring Sound with PhET**
  - Sound is a mechanical wave which transfers energy to the surrounding medium. We typically think of the medium as air; however, sound can also propagate in other media such as liquids or solids.
  - A slinky wave can be used as a model for a sound wave. A wave is created within the slinky when one end of the slinky is pushed causing a back and forth motion of the first coil which begins to alternately ‘push’ and ‘pull’ on the second coil. The push and pull disturbance moves through the slinky as each coil is displaced from its original [equilibrium] position. As you can see in the image above, there are regions of compression [the particles are close together] and other regions where there is little compression called rarefaction [particles are farthest apart]. Notice the diagram of a longitudinal wave shown above.
  - Sound propagates through the air as a longitudinal wave when air particles transfer the energy as the particles collide with one another. The following brief YouTube video [see the following URL](https://www.youtube.com/watch?v=Bcqp6t4ybxU) provides an explanation for sound as a mechanical wave using a slinky as the model:
  - The PhET link: [https://phet.colorado.edu/en/simulation/legacy/sound](https://phet.colorado.edu/en/simulation/legacy/sound) is a way to engage students with a virtual simulation of sound as a mechanical wave.
  - At this station, students will have the opportunity to manipulate multiple
aspects of sound including frequency and amplitude. Students will also be able to determine how variations in air pressure impacts sound. The PhET simulation model notes that changes in air pressure result in changes within the gaseous medium through which sound travels. This model demonstrates that sound requires a medium to propagate. Students will be able to remove all of the air from the virtual sound box and observe changes in air pressure indicated by the dial above the speaker.

- When manipulating frequency and amplitude, students will be able to observe changes in the representations of sound waves and also hear the resulting changes in the sounds generated.
- PhET simulations allow students to gain experience with technology, reinforce understanding of sound as a mechanical wave, and address misconceptions about sound.

<table>
<thead>
<tr>
<th>Something to think about</th>
<th>Statement: Sound is a mechanical wave.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>o Both frequency and amplitude alter the sounds we hear. The PhET Sound Simulation allows students to explore sound and make and test predictions of how the sound and the resulting virtual model sound waves will change when the frequency, amplitude, or air pressure are manipulated.</td>
</tr>
<tr>
<td></td>
<td>o Frequency: Sound waves are actually a transfer of energy as the sound travels away from a vibrating source. The source could be the sound a whistle makes or the sound of the human voice. The Frequency refers to the speed of the sound or the number of vibrations that an individual particle makes in a specific period of time [typically one second].</td>
</tr>
<tr>
<td></td>
<td>▪ When students manipulate the PhET simulation, they will note that there are more sound waves within the same space at higher frequencies and a lower number of sound waves within the same space at lower frequencies.</td>
</tr>
<tr>
<td></td>
<td>▪ Note that as the frequency increases, the sound waves become increasingly close to one another.</td>
</tr>
<tr>
<td></td>
<td>▪ The students will hear a sound with an increasingly higher pitch as the frequency increases.</td>
</tr>
<tr>
<td></td>
<td>o Amplitude: Amplitude refers to the size of the vibration and, therefore, determines the loudness of the sound. Note the diagram below. The sound waves on the left are identified and low amplitude and those on the right are examples of high amplitude.</td>
</tr>
<tr>
<td></td>
<td>▪ Another way to think about amplitude is that the size of the vibration changes with changes in amplitude. So a sound with lower amplitude would be a soft sound whereas a sound with higher amplitude would be a louder sound.</td>
</tr>
<tr>
<td></td>
<td>▪ Ask students to note the changes in sound they hear when manipulating the amplitude in the PhET simulation.</td>
</tr>
</tbody>
</table>
|                          | o Air Pressure: It is important to note that sound requires a medium such as air, liquid, or solid to travel over distance and to be heard. If the air pressure is decreased, the sound diminishes until the number of air
particles become so small that sound waves can no longer travel. Outer space is a vacuum and, therefore, there is no sound. Explosions in space are seen but not heard.

| **Exploring Sound with Technology and Linking to the Standards** | Next Generation Science Standards:
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.

**Disciplinary Core Ideas:**
- Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks). (4-PS4-1)

**Science and Engineering Practices:**
- Develop a model using an analogy, example, or abstract representation to describe a scientific principle.

**Crossteaching Concepts:**
- Similarities and differences in patterns can be used to sort, classify, and analyze simple rates of change for natural phenomena.

| **Assessment** | Formative assessment is suggested:
- Use the questions suggested at each step as a means to assess students’ understanding.
  - Challenge students to collaborate in teams to analyze and interpret their data to develop supporting evidence which describes sound as a mechanical wave. |
Sound Science: Exploring Sound with PhET, a virtual simulation [Teacher page]

**Frequency:**

Click on the ‘Listen to a Single Sound Source’ Tab at the top of the PhET window. **[Note: be sure to click the Audio Enabled box to hear the sound.]**

- The image in the figure to the left is what students will see when they click on the ‘Listen to a Single Sound Source’ tab.
- Students will be able to manipulate both frequency and amplitude by moving the arrows on the Frequency and Amplitude controls on the right side of the screen.
- Change the frequency first by moving the arrow. Listen to the change in the sound and watch for changes in the sound waves.

**Questions:**

1. Listen to the sound and carefully observe the sound waves before moving the arrow. Now, move the Frequency arrow to the right. How does the sound change?
   a. The sound becomes lower [has a lower pitch].
   b. The sound becomes higher [has a higher pitch].
   c. There is no change in sound.

2. Next, think about the sound waves. How do the sound waves coming from the speaker change when the arrow is moved to the right?
   a. The sound waves are closer together, there appear to be more sound waves.
   b. The sound waves move farther apart, there appear to be fewer sound waves.
   c. There is no change in frequency when the arrow is moved to the right.

3. Why do you think this happens? When the frequency of the sound produced is increased by moving the arrow to the left, there are more sound waves produced by the PhET simulation in the same period of time. This change causes the sound created by the simulation to have a higher pitch. Higher pitch
sounds have an increased frequency of sound waves. In other words, you will notice that there are more sound waves within the same space.

4. How do the sound waves coming from the speaker change when the arrow is moved to the left? Why do you think this happens?

When the frequency of the sound produced is decreased or lowered by moving the arrow to the right, there are fewer sound waves produced by the PhET simulation in the same period of time. This change causes the sound created by the simulation to have a lower pitch. Lower pitch sounds have a lower frequency of sound waves. You will notice that the distance between the waves pictured in the simulation increases as the frequency of the sound is lowered.

Amplitude:

Once again, click on the ‘Listen to a Single Sound Source’ Tab at the top of the PhET window. **[Note: be sure to click the Audio Enabled box to hear the sound]**

- Click on the Audio enabled box
- Move the Amplitude arrow to the right. Leave the Frequency arrow in the center of the scale.

Questions:

5. Listen to the sound and carefully observe the sound waves before moving the arrow. Now, move the Amplitude arrow to the right. How does the sound change?
   a. The sound becomes lower [has a lower pitch].
   b. The sound becomes higher [has a higher pitch].
   c. There is no change in sound.
6. Next, think about the sound waves. How do the sound waves coming from the speaker change when the Amplitude arrow is moved to the right?
   a. The sound waves are closer together, there appear to be more sound waves.
   b. The sound waves move farther apart, there appear to be fewer sound waves.
   c. There is no change in frequency when the arrow is moved to the right.

7. Why do you think this happens?
   Amplitude refers to the volume of the sound produced. Notice that when amplitude arrow is moved to the right the sound is loud and easy to hear. Also note that the sound waves are more clearly defined.

8. How do the sound waves coming from the speaker change when the Amplitude arrow is moved to the left?
   Amplitude refers to the volume of the sound produced. Notice that when amplitude arrow is moved to the left the sound is softer. If the arrow is moved to the left side of the scale, the sound will no longer be audible. Also note that the sound waves are less clearly defined and will no longer be visible if the arrow is moved to the left end of the scale.

**Listening with Varying Air Pressure**

During this activity, you will vary the air pressure within the PhET Sound Box. To do this click on the Listen with Varying Air Pressure tab. You will go to a new window with a speaker and an air pressure gauge. During this investigation you will have the opportunity to change the air pressure within the sound box and then remove all air from the sound box.

The image above is what you will see after clicking on the ‘Listen with Varying Air Pressure’ tab. Both the Frequency and Amplitude arrows should be in the center of the scale. After clicking on the Remove Air from Box button, watch the air pressure gauge, the red needle will go to zero as all of the air leaves the box.
Sound Science: Exploring Sound with PhET [Student pages]

Name: ________________________________

Frequency:
Click on the ‘Listen to a Single Sound Source’ Tab at the top of the PhET window. [Note: be sure to click the Audio Enabled box to hear the sound.]

Questions:
1. Listen to the sound and carefully observe the sound waves before moving the arrow. Now, move the Frequency arrow to the right. How does the sound change?
   a. The sound becomes lower [has a lower pitch].
   b. The sound becomes higher [has a higher pitch].
   c. There is no change in sound.

2. Next, think about the sound waves. How do the sound waves coming from the speaker change when the arrow is moved to the right?
   d. The sound waves are closer together, there appear to be more sound waves.
   e. The sound waves move farther apart, there appear to be fewer sound waves.
   f. There is no change in frequency when the arrow is moved to the right.

3. Why do you think this happens?

4. How do the sound waves coming from the speaker change when the arrow is moved to the left?
   a. The sound waves are closer together, there appear to be more sound waves.
   b. The sound waves move farther apart, there appear to be fewer sound waves.
   c. There is no change in frequency when the arrow is moved to the right.

5. Why do you think this happens?
Amplitude:
Once again, click on the ‘Listen to a Single Sound Source’ Tab at the top of the PhET window.

[Note: be sure to click the Audio Enabled box to hear the sound]

Questions:
6. Listen to the sound and carefully observe the sound waves before moving the arrow. Now, move the Amplitude arrow to the right. How does the sound change?
   a. The sound becomes lower [has a lower pitch].
   b. The sound becomes higher [has a higher pitch].
   c. There is no change in sound.

7. Next, think about the sound waves. How do the sound waves coming from the speaker change when the Amplitude arrow is moved to the right?
   a. The sound waves are closer together, there appear to be more sound waves.
   b. The sound waves move farther apart, there appear to be fewer sound waves.
   c. There is no change in frequency when the arrow is moved to the right.

8. Why do you think this happens?

9. How do the sound waves coming from the speaker change when the Amplitude arrow is moved to the left?
   a. The sound waves are closer together, there appear to be more sound waves.
   b. The sound waves move farther apart, there appear to be fewer sound waves.
   c. There is no change in frequency when the arrow is moved to the right.

10. Why do you think this happens?

Listening with Varying Air Pressure
During this activity, you will vary the air pressure within the PhET Sound Box. To do this click on the Listen with Varying Air Pressure tab. You will go to a new window with a speaker and an air pressure gauge. One of the themes throughout the sound activities has been the importance of a medium for conducting sound waves. We explored multiple materials as conductors of sound waves including: tuning forks, water, plastic wrap, sugar crystals, string, and plastic cups. During this investigation you will have the opportunity to change the air pressure within the sound box and even remove all air from the sound box.
Questions:

11. Make a prediction. What do you think will happen when the air leaves the box?

If all of the air leaves the box, then _____________________________

12. Now test your prediction by clicking on the ‘Remove the Air from the Box’ button shown in the image above.

a. What happened to the sound as the air left the box?

b. When the red needle in the Air Pressure Gauge pointed to zero and all of the air had left the box, could you still hear a sound? _____

i. Did this observation support your prediction? _____

ii. Why do you think this happened? Use evidence from your experiences with sound to support your answer.
# Exploring Sound with Technology

## Activity Overview
The goal of this activity is to provide students with the capacity to explore sound using the *Twisted Wave* app. With this technology, students will be able to observe a digital representation of their own voices. This unique app allows any sound to be recorded and edited. We will use this app to engage students with a two-dimensional model of the sound wave. It is important to point out to students that the app does not provide a three-dimensional view of the sound wave. This app can be downloaded at no charge from iTunes for Mac + PC. The URL is: [https://itunes.apple.com/us/app/twistedwave-audio-editor/id401438496?mt=8](https://itunes.apple.com/us/app/twistedwave-audio-editor/id401438496?mt=8) [preload the app on to iPads for use in the classroom]

## Materials
Laptops, tablets, smart phones

## Guiding Question
How do sound waves change with changes in our speech? For instance, do sound waves of a high pitched voice [young child] look different from sound waves of a deep voice [adult male]?

## Exploring Sound with Technology

**Exploring Sound with Technology**
- Using the *TwistedWave Recorder* app ask students to record their own voices. They will be able to see two-dimensional digital representations of the sound of their voices. Students can compare a high pitched voice with a deeper, lower pitch voice. The students will note variation in the appearance of the digital models generated as different sounds are recorded and displayed by the app.
- Loud sounds are deeper sounds, like a man’s voice. Soft sounds are high pitch sounds like a young girl’s voice. Ask students to study the images of sound generated by the app and see how the digital representations of sound provided by the *Twisted Wave Recorder* app differ.

## Something to think about
Sound is something that most of us take for granted. We hear an array of sounds every day and we do not really think about what we are hearing sound is just another part of our world.
- When a sound is created, the sound itself is a vibration also known as a mechanical wave. Why call sound a mechanical wave? Because sound waves transfer energy and can make other materials [like gases, liquids, and solids] vibrate as well.
- When sound travels, it causes the molecules or particles of air to vibrate. Eventually, the vibration reaches our ears. Sound waves cause the eardrum to vibrate and that vibration is conducted to three tiny bones behind the eardrum which conducts the vibration into the inner ear. Nerves in the inner ear are stimulated by the vibration and a nervous impulse travels to our brain where meaning is formulated.
Exploring Sound with Technology: Twisted Wave Recorder App (Teacher Page)

You will use the TwistedWave Recorder App to conduct an exploration of sound. Use the iPad and this App to make and test predictions about sound.

Everyone in your team should take a turn and speak into the iPad. The TwistedWave Recorder App will convert the sound of your voice into a two-dimensional digital representation of sound waves.

Questions:

1. How does a loud sound look different from a soft sound?
   a. After watching each person in your team speak into the iPad, do you have any evidence to support your claim?

Loud sounds will translate into more prominent waves, the waves have larger amplitude. Whereas a softer sound would have low peaks or low amplitude.

![Loud sound](image1)

![Soft sound](image2)

2. How does a high-pitched sound look different from a low-pitched sound? Provide evidence to support your claim.

High-pitched sound will have more waves squeezed together (high frequency) whereas a low-pitched sound will have waves further apart (low frequency)
Visualizing Sound Using Technology: TwistedWave App

You will use the TwistedWave App to visualize the sound of your voice and the voices of your friends. This is an interesting exploration of sound. Use the iPad and this App to make and test predictions about sound.

Everyone in your team should take a turn and speak into the iPad. The TwistedWave Recorder App will convert the sound of your voice into a digital representation of sound waves. This app is very similar to the technology used by recording studios when artists record music.

Questions:

1. How does a loud sound look different from a soft sound?
   a. After watching each person in your team speak into the iPad, do you have any evidence to support your claim?

2. How does a high-pitched sound look different from a low-pitched sound? Provide evidence to support your claim.