Sound and Light

A Middle School Physical Science Unit on Waves

Lesson #	Lesson Title	Suggested Time
1	Flash! Kaboom	45 minutes
2	The Sound of Fury	2 x 45 minutes
3	An Impactful Event	2 x 45 minutes
4	Feeling the Pressure	2 x 45 minutes
5	Traveling On…	2 x 45 minutes
6	Bouncing Back…	2 x 45 minutes
7	…or Standing Still?	2 x 45 minutes
8	Matter Matters	2 x 45 minutes

Driving Questions

What are waves and how can we describe them? How do waves transfer Energy? How do waves move through different states of matter? What are the differences between matter wave (sound, water, seismic) and electromagnetic waves (light)? What are some natural or man-made applications involving waves?

Anchoring Phenomenon (Flash! Kaboom!)

How and why does it work that you can approximate the distance to a thunderstorm by counting the seconds between a flash of lightning and the kaboom of thunder?

Sound and Light

Standards Addressed in the Unit

By the end of the unit, students should demonstrate full mastery of:

MS-PS4-1	Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.
MS-PS4-2	Develop and use a model to describe how waves are reflected, absorbed, or transmitted through various materials.
MS-PS4-3	Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals.

Students should demonstrate mastery of some components of:

MS-PS3-5	Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.
MS-ESS3-2	Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.

3-dimensional Learning Matrix

Lesson	*Primary Standard*	*Science/Engineering Practices*	*Crosscutting Concepts*
1	*MS-ESS3-2. Natural Hazards and Mitigation*	• *Analyze and interpret data* • *Develop and use models*	• *Patterns* • *Systems & System Modeling*
2	*MS-PS3-5. Energy Transfer*	• *Ask questions* • *Develop and use models*	• *Cause and Effect* • *Patterns* • *Scale, Proportion & Quantity*
3	*MS-PS3-5. Energy Transfer*	• *Plan and carry out investigations* • *Construct explanations*	• *Cause and Effect* • *Energy and Matter*
4	*MS-PS4-1. Models of Waves*	• *Develop and use models* • *Plan and carry out investigations* • *Use mathematical representations*	• *Cause and Effect* • *Energy and Matter*
5	*MS-PS4-1. Models of Waves*	• *Develop and use models* • *Plan and carry out investigations* • *Use mathematical representations*	• *Patterns*
6	*MS-PS4-2. Wave Properties at Boundaries*	• *Develop and use models* • *Plan and carry out investigations*	• *Cause and Effect* • *Energy and Matter*
7	*MS-PS4-2. Wave Properties at Boundaries*	• *Plan and carry out investigations* • *Analyze and interpret data*	• *Cause and Effect*
8	*MS-PS4-2. Wave Properties at Boundaries*	• *Develop and use models* •	
9	*MS-PS4-2. Wave Properties at Boundaries*		

Lesson 1	Flash! Kaboom!
Overview Standard(s) & Objectives	**Overview** How can the difference between what our eyes see and our ears hear tell us about the distance to a nearby thunderstorm? Students are introduced to an anchoring phenomenon, which will be referred to throughout the unit. We make observations of thunderstorms. Does it work that you can approximate the distance to a thunderstorm by counting the seconds between a flash of lighting and crash of thunder? Is it just an old wife's tale? After collecting data to explore the phenomenon, students will make a model of the phenomenon. **Building Toward** **MS-PS4-1, MS-PS4-2, MS-PS4-3** Plan and carry out an investigation to describe and classify different kinds of materials by their observable properties. Crosscutting Concept/SEPs • Asking Questions about Patterns in Observations • Collect and Analyze Data • Develop a Model **Where We Are Going** In this unit, the primary learning intention is for students to be able to demonstrate full mastery of three middle school science standards on waves (MS-PS4.1, MS-PS4.2 and MS-PS4.3). To demonstrate mastery, students will be able to: • use qualitative and quantitative (mathematical representations) thinking to model matter waves. (MS-PS4.1) • model (qualitatively) the interaction of both matter and electromagnetic waves with different materials. (MS-PS4.2) • integrate qualitative scientific and technical information to support the claim that waves can be used for communication purposes and have other applications in society. (MS-PS4.3) By matter waves, we refer to waves that require matter to transmit energy (sound, seismic, or water). By electromagnetic waves, we refer to light and nonvisible parts of the electromagnetic spectrum. Throughout the unit, students will study the properties of sound waves and how they interact with matter, with an extension to seismic waves. Then they will extend their studies to electromagnetic waves interacting with matter. They will research applications of waves for society and for the science and engineering being pursued deep underground at Sanford Underground Research Facility.

Lesson 1 elicits students' initial ideas and questions about sound and light and the differences between the two. In this lesson students are introduced to the anchoring phenomenon —the Flash-to-Bang technique for approximating the distance to a thunderstorm. In order to understand this phenomenon, students will need to explore both qualitative and quantitative properties of matter (sound) and electromagnetic (light) waves that affect their transmission through air and other media.

Students may come to this unit with prior knowledge and experiences that can be leveraged. Remember not to let words or representations in students' models signal a false understanding of how sound or light works on a deep, mechanistic level.

For example, it is unlikely coming into the unit that students are thinking of the sound waves as an emergent phenomenon that is a result of how particles of matter interact with each other. It is far more likely that they heard or read about sound being a wave or have seen a wave-like icon on their stereos or phones that represents sound. It's important to keep pushing students to define what these waves are and how they travel and how waves transfer energy from the source of the thunder to our ears.

Likewise, students may have studied light in earlier grades but may not have yet developed mental models of light as a wave with defined properties that affect how it interacts with matter.

In this initial lesson, students will begin asking specific questions that can lead them to consider gaps in their mental models that can be investigated by the class in subsequent lessons. Some examples are:

- *What is sound? What causes sound? How does it travel through the air? How is the sound of thunder made during a thunderstorm?*
- *What is light? How does it travel through the air? How is the flash of lightning made during a thunderstorm?*
- *Are the lightning and thunder made together at the same time, or is the thunder made later?*
- *What are the differences between light waves and sound waves? Do they move through air and other materials differently?*

The phenomenon of a thunderstorm is introduced as a natural hazard familiar to all students in South Dakota and the region. The flash-to-bang technique they will dissect is highly useful for estimating potential risk from lightning.

Where We Are Not Going

Beyond the initial conditions that create the sound or electromagnetic waves to be studied, this lesson and unit will not include the mechanics of thunderstorms. The mechanics of how lightning and thunder are produced will be introduced at a very basic level.

Assessment Opportunities

Observing:

- Each student has written down Notices/Wonders in their science notebook.

Investigating:

- Each student has completed prediction/data table in their notebook.

<table>
<tr><td></td><td>Modeling:
Students have thought of one or two more related phenomenon and written them down.
On their initial diagram, students have attempted to draw what might be happening for sound at the source, detector, and the space between.</td></tr>
<tr><td>Materials</td><td>Per Student:
Science Notebook (teacher provided)
Initial Model Diagram
Per Pair of Students:
Timer
Task Card 1
Calculator (teacher provided)
Per Classroom:
PowerPoint
Chart Paper (teacher provided)
Markers (teacher provided)
Computer/Projector (teacher provided)</td></tr>
<tr><td colspan="2">Prework</td></tr>
<tr><td>Setting Up a Science Notebook</td><td>1. Introduce the new unit of study by passing out a Science Notebook to each student. If students are not currently using science notebooks, you can include additional time to organize them. Have students organize their notebooks using a format that will be easy for them and you to maintain. Here are some helpful tips for keeping the notebooks organized*:

a. Number pages so students can easily refer to their work (models, data sets, and so forth) during collaborative discussions.

b. Maintain and update a table of contents throughout the unit. Reserve at least 4 pages (2 pages front and back) for the table of contents for a single unit. The table of contents can be at the front of the notebook for all units within or at the beginning of each new unit within the notebook.

c. Give each page a recognizable title that can be added to the table of contents.

d. After the table of contents, reserve the next 20 pages (10 pages front and back) for their Progress Tracker for the unit. This is the place where students will individually reflect on their progress and add key consensus modeling work completed by the class.

e. Make the last several pages of the notebook a glossary. Students will use their own words to write definitions of science terminology and concepts.

(Optional) If students have not previously used science notebooks, the video Science Notebooking – How I Use My Science Notebook** from the California</td></tr>
</table>

	Academy of Sciences** (linked from the lesson PowerPoint file **(Slide 2)** and in the Video folder on the unit flash drive).
Resources and Strategies	Check out the Science Notebook Corner at the California Academy of Science for many helpful videos and hints: https://www.calacademy.org/educators/science-notebook-corner
Part 1. What do we notice/observe about thunderstorms? Materials: Computer, Projector, Whiteboard (or Chart Paper & Markers)	
Student Practices	• Observe Thunderstorms • Construct Explanations
Instructions	*DRIVING QUESTION: What do we notice and observe about thunderstorms?* 1. Tell students that you recently saw a video of a natural phenomenon that everyone is familiar with in South Dakota, and you noticed some interesting details. Show **Slide 3** and ask students to create a T-chart in their science notebooks to record what they notice and wonder about in the video the class will be watching together. Play the video on a loop while students watch and write their notices and wonders. *The video is linked from **Slide 3.*** <table><tr><th>Notice</th><th>Wonder</th></tr><tr><td>**I notice ...**</td><td>**I wonder ...**</td></tr></table> **2.** Once students have had enough time to closely observe this phenomenon, instruct them to share their notices and wonders with a partner. Questions on **Slide 4** can be used to frame their discussions. 3. Randomly choose pairs to share one **notice** with the classroom and write in a list on the board or on chart paper. Halfway through switch to **wonders** and start a new list. Circle any notices or wonders in the list that have to do with time or distance. Then ask students if anyone knows how to tell how far away a thunderstorm is? Many students have probably been told by their parents that they can count the time between the lightning and the thunder. Write down any variations of this students have on the board or another piece of chart paper, then have a class discussion. What do they think? Is this an old wife's tale, or do they think it works? Poll the class with a fist or five (fist is no, it won't work; five is yes it does).
Resources and Strategies	**Think-Pair-Share (TPS)** is a learning tool developed by Frank Lyman, a professor at the University of Maryland in 1981. It helps foster independent thinking and collaboration in classroom discussions. Helpful hints for using TPS can be found at **https://www.wgu.edu/heyteach/article/how-think-pair-share-activity-can-improve-your-classroom-discussions1704.html**
Part. 2 How can we figure out the distance to a thunderstorm by using our senses and math? **Materials: Computer, Projector, Task Card 1, Timer, Calculator**	

Student Practices	- Make Predictions - Collect and Analyze Data - Connect to Math - Brainstorm
Instructions	*DRIVING QUESTION: How can we figure out the distance to a thunderstorm by using one or more senses and simple math?* 1. *(Note: the volume should be muted in video 4, but you may want to check).* **Pass out a task card to each student**. Have students copy the data table into their notebook or use Data Sheet-1 from the Print masters, then play the new video (**linked from Slide 5)** of five different lightning strikes (no sound!). Loop it through a few times while students do Part A of the task card on their own looking for clues that will tell them which lightning strikes are closer and which are farther away. The lightning flash for storm 3 is a very short flash, it may not appear on some computers due to the video refresh rate on the computer. The students may have to watch #3 several times to see the lightning bolt on the left side of the video. 2. Ask students to compare their prediction with their partner. They should discuss the clues they used to decide the order. If they did not predict the same order, why not? *Keep the video looping in case they want to check something together.* Then have each pair on the right side of the room move across to the left to find another pair and discuss the predictions again. Did the other group notice different clues? 3. After the discussion, have students return to their desks and individually modify their prediction based on their discussions (if they wish). Then play the video again with the volume up **(Slide 6)**. Students will take turns measuring the time difference between the lightning and the thunder for each example. One student will use the timer to measure the time between each lightning flash and sound of thunder, and their partner will write it down. On the second time through, switch roles. Then students should complete their data tables and average their results. To calculate the average, add both times and divide the number by 2. ex. 4 seconds + 6 seconds = 10 seconds /2 = 5 seconds average time. 4. Have students (in their notebooks) individually compare their measurements and predictions and answer the reflection questions using the prompts on **Slide 7 or on the bottom of the data sheet.** 5. Then, using **Slide 8**, define the scientific term **correlation.** Students will decide whether there is a positive, negative, or no correlation between the time between the lightning and thunder and their predicted distance. A correlation may be a clue that there is a **cause-and-effect** relationship between two variables, but not necessarily (they could both be independent effects of another cause). **6.** Have students think about related phenomenon to the lightning/thunder system and write an example in their notebook. *Examples could be anything involving a time delay between what you see and hear, for example fireworks, or the national anthem in a*

	football stadium. Have a few people share out and write their examples on the board. In a class discussion, ask students to make **analogies (Slide 9)** between the thunder and lightning and a couple of the examples from the board. Then give students a minute to write down an analogy table for their own example.
Resources and Strategies	**Think-Pair-Square-Think –** There are many variations of TPS. In the case of comparing predictions, we like this one. It gives students an opportunity to talk about their reasoning twice and then gives them the option to change their prediction if they wish. This strategy works in cases where it is not important that the class come to consensus. When brainstorming related phenomena, students can leverage lived experiences that are personally and culturally meaningful to them to generate an expanded sphere of phenomena that the class will work together to explain. Including this routine in Lesson 1 allows students to share the understanding and perspective they bring to the classroom with their classmates and promotes engagement since the class's work will be leveraged to explain something meaningful to each student.
Part 3. How can we make an initial model of the Flash-to-Bang phenomenon? **Materials: Computer, Projector, Calculator, Initial Model Diagram Handout**	
Student Practices	• Develop an Initial Model
Instructions	*DRIVING QUESTION: How can we make an initial model of the Flash-to-Bang phenomenon?* 1. There is a scientific term for determining how far away a thunderstorm is by counting seconds, called **Flash-to-Bang**. Play the video, '*How far away is Lightning?',* linked from **Slide 10.** Students should write down the formula in their notebook: *#seconds between/5 = number of miles away* and use it to convert their measured times into distance. *NOTE: An answer key is included on the Flashdrive in the Teacher Resources folder.* 2. Ask students to spend a couple of minutes reflecting on what they have done so far in this lesson by using the prompts on **Slide 11** to write down two to four sentences (students can use any sentence starter multiple times and skip some if they wish). 3. Students will begin a **scientific model** of sound (we will come back and do the same thing for light later in the unit) that they will continue to develop and refine throughout the unit. While students are reflecting, pass out the ***Initial Model Diagram**** handout. Students will use the handout and their ideas to make an annotated drawing of the sound portion of the thunderstorm system – at the source (thunderstorm), detector (the video camera) and all points in between. This initial model will be an indicator of students' prior knowledge about sound and waves. Success criteria for the initial modeling activity include: a. Students should make an attempt to show what's happening at a zoomed-in scale at three places: at the storm, in the air between

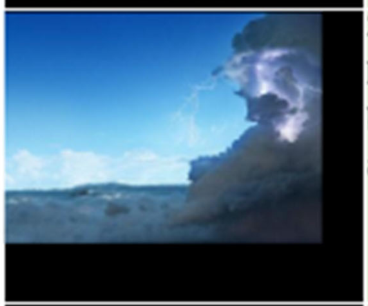
	the storm and the video camera, and at the video camera or observer. b. There might be points where students need to show something they can't see. Remind students that they can use pictures, symbols, and labels to represent components they can't see. c. The lines below each section should be utilized to write a short caption explaining what they think is happening in their model. This will support their explanation and make their thinking clearer to people who might not understand their drawing alone. 4. While students are drawing their models, walk around the room and quietly ask probing questions if there are no labels on the models. Suggested prompts: a. Where is the sound coming from in your model? b. How are you showing the sound moving to the camera (or person)? Can you label that? c. What do you think is happening at the camera (or person)? Can you show that? 5. Once finished, have students tape their handout into their Science Notebook.
Science Terminology and Concepts	**Flash-to Bang –** The <u>Flash-to-Bang</u> phenomenon is a way to estimate how far away a thunderstorm is. Each five second difference between the lightning flash and the thunder clap correlates to approximately 1 mile distance. **Correlation –** In science, a <u>correlation</u> is a relationship between two variables used to describe or predict information. A positive correlation means both variables increase together. A negative correlation means that one decreases as one increases. **Cause and Effect -**a relationship between actions or events in which at least one action or event is a direct result of the others. **Analogy -** An <u>analogy</u> is a comparison between two objects, or systems of objects, that highlights respects in which they are thought to be similar. **Scientific Model** - A <u>scientific model</u> is a physical, conceptual, or mathematical representation of a real phenomenon that is difficult to observe directly.
Resources and Strategies	*✱ SUPPORTING STUDENTS IN DEVELOPING AND USING MODELS* Scientists use models to explain why and how phenomena occur as they do. Scientists continually revise their models as they get new information and data. Models need to be "applied" to be useful in explaining something, and models are most helpful when they can help us explain a lot of similar phenomena. Because students are just starting to develop their initial models, they may not be able to explain many parts of the phenomenon with confidence, and that is OK. Students will continue to revise and edit their model over the course of the unit. **Sentence Frames (I noticed/I learned/ I wonder/ I think)** is one of several reflection tools that have been developed to help students realize just how much they have learned after a science lesson and to give them an opportunity to revise initial misconceptions. Using four phrases as sentence frames, students can select which ones

	and how many they would like to use without limitations. They may have a lot of 'wonders' and no 'learns' and you can ensure them that is fine. More ideas: https://www.calacademy.org/educators/reflecting-on-content-learned

Sound and Light

Name: ________________________________ Date: ____________________

Initial model: What do you need to figure out about sound to answer the question: *How does it work that you can tell how far away a thunderstorm is by measuring the time between the lightning flash and the thunder?* For each location on your model, show a zoomed-in view of what is happening. Then, explain your model in words.

	Location	SOUND	
		Diagram	Description
	Zoom in on what is happening at the source of the sound (the thunderstorm).		
	Zoom in on what is happening in between the source and the detector.		
	Zoom in on what is happening at the detector of the sound (videocamera or ears of observer).		

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Task Card 1, Part A
Flash! Kaboom!

DRIVING QUESTION. Can we figure out just by looking how far away a thunderstorm is?

MATERIALS: *Science notebook, ruler to draw your table*

1. THINK (ON YOUR OWN)

- Copy the data table on the back of this card into your notebook.
- Your teacher will play a loop of a video of five thunderstorms, with no sound. Watch it a few times. Are their clues that could help you decide how far away the storm is? Write them down for each storm, then predict the order of the storms, from farthest to nearest.

2. PAIR (WITH A PARTNER)

- Compare your prediction with a partner. Did you predict the same order? Discuss the clues you used when you made your prediction.

3. SQUARE (MEET WITH ANOTHER PAIR)

- When your Teacher Tells you To, as a pair, move across the room and find another pair to compare predictions with.

4. THINK (ON YOUR OWN)

- Now that you have discussed it with your partner and another pair, change your predictions if you wish.

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3. SQUARE (MEET WITH ANOTHER PAIR)

- When your Teacher Tells you To, as a pair, move across the room and find another pair to compare predictions with.

4. THINK (ON YOUR OWN)

- Now that you have discussed it with your partner and another pair, change your predictions if you wish.

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Task Card 1, Part B
Flash! Kaboom!

DRIVING QUESTION. Using our eyes AND our ears can we figure out how far away a thunderstorm is?

MATERIALS: *Science notebook, timer, calculator*

WORKING WITH THE SAME PARTNER:

- Observe the video again, this time with sound. Your teacher will run it in a loop.
- One person will time each thunderstorm, starting at the flash of lightning and ending at the thunder. Practice a few times first. Their partner will write down the times in the column labeled 'MY PARTNER'.
- Switch roles.
- When each person has a set of data they are satisfied with, copy the full data, then average the numbers.
- Compare with your predictions.

DATA TABLE

Storm #	Clues	Time (my partner)	Time (me)	Average time (sec)	Prediction(F-N)	Rakn by time

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Task Card 1, Part B
Flash! Kaboom!

DRIVING QUESTION. Using our eyes AND our ears can we figure out how far away a thunderstorm is?

MATERIALS: Science notebook, timer, calculator

WORKING WITH THE SAME PARTNER:

- Observe the video again, this time with sound. Your teacher will run it in a loop.
- One person will time each thunderstorm, starting at the flash of lightning and ending at the thunder. Practice a few times first. Their partner will write down the times in the column labeled 'MY PARTNER'.
- Switch roles.
- When each person has a set of data they are satisfied with, copy the full data, then average the numbers.
- Compare with your predictions.

DATA TABLE

Storm #	Clues	Time (my partner)	Time (me)	Average time (sec)	Prediction(F-N)	Rakn by time

Lesson 2	The Sound of Fury
Overview Standard(s) & Objectives	**Overview** What are the properties of sound we need to understand to explain the thunderstorm and related phenomena? We develop an initial list of questions that we need to understand to figure out what is really happening when the sound produced in storms travels through the air to our detector (microphone/camera or eyes/ears). Then we start our investigation with the question of what produces sound. We begin our exploration by using tuning forks and develop a model to produce sound by vibrations in a tuning fork and other objects. **Building Toward** **MS-PS3-5** Crosscutting Concept/SEPs • Asking Questions, Cause-and-Effect • Conduct Investigations • Develop a Model **Where We Are Going** At the end of Lesson 1, students developed an initial model, in which they divided the problem of understanding the Flash! Kaboom! Phenomenon into two major categories: understanding sound (thunder) and understanding light (lightning). Focusing on sound, they further divided the model construction into understanding the production, transmission, and detection of the sound of thunder. Students begin Lesson 2 by asking the questions that must be answered to figure out the sound part of the phenomenon. These questions will be divided into categories based on the model construction and addressed at appropriate times as the unit progresses. The first step in this process will be to figure out what causes sound in general and thunder in particular. A big building block of the science developed in this lesson is that a sound is first generated by kinetic energy transfer to an object in the system. The force applied by tapping the tuning fork transfers energy into one tine of the fork and starts them vibrating. Students may just call this force a “push” or “impact” at this point, and this language is fine; what’s important is the conceptual understanding of energy input into the system. Something must be done (push, pull, impact, force) to the object to make the sounds. **Where We Are Not Going** In future lessons we will get to the idea that the vibration set up in an object like a tuning fork causes the particles of the medium (air in this case) to compress and then expand, bumping into their neighbors. The resulting periodic compressions and decompressions result in a sound wave. Without noting the deformation beyond the original starting position, it’s difficult to explain why the particles of air or other media are affected by an object vibrating. This deepening definition of vibration also sets up an understanding

	that will be developed in grades 9-12 regarding the intermolecular forces that are at play. Although this intermolecular understanding is beyond this grade band, one can see the learning progression of the definition of vibration. In high school physics classes and beyond, this mechanism will also help account for normal forces on objects at rest on the ground. Students will return to the lightning part of the phenomenon in Lesson 9, after they complete an in-depth study of matter waves.
Assessment Opportunities	**Questioning:** • Check that each student has completed their self-assessment of their model and written down three thoughtful questions about the thunder portion of the phenomenon in their notebooks (one on production, transmission, and detection of sound) **Investigating:** • Observe that each student is engaged in the investigation. • Check that each student has a completed data table in their notebook. **Modeling:** • Step 4 of the graphic organizer • Transfer of learning from tuning forks to guitar strings (formative assessment)
Materials	Per Student: • Science Notebook • Marker • Task Card 2-2 • Lesson 2-2 Data Table (print master) • 15-cm ruler • Scale, Proportion, Quantity graphic organizer Per Group (4 to 5): • Bundle of Tuning Forks (4) • Thumper • Tub half-filled w/ water • Paper Towels (teacher provided) Per Classroom: • Chart Paper (teacher provided) • Computer, Projector (teacher provided) • PowerPoint • Extra Tuning Forks (3)
Preparation	• The room should be set up for groups of four around tables or lab benches (if possible). FOR PART 1: Prepare three sheets of chart paper with the titles shown below:

SOUND Source	SS	SOUND Detector	SD	SOUND In between	SB

FOR PART 2: Print a *Lesson 2 Data Table* for each student. Have rulers and tuning forks ready to go. Have a tub half filled with water and a pile of paper towels ready to go.

FOR PART 3: Print a *SPQ Graphic Organizer* for each student.

Part 1. What do we need to figure out about how the sound of thunder is produced, transmitted through the air and detected in order to begin to understand Flash-to-Bang phenomenon?

Materials: Pre-prepped Chart paper, Markers

Student Practices

- Ask questions about the phenomenon

Instructions

DRIVING QUESTION: What do we need to figure out about how the sound of thunder is produced, transmitted through the air and detected in order to begin to understand the Flash-to-Bang phenomenon?

1. Have students open their notebooks to the **initial model diagram from Lesson 1** and review what they drew and wrote. Then put up **Slide 2.** Students will follow the task on the slide and do a self-assessment of how confident they are about the three parts of the model (source, in between, detector). Then ask them to think of one question they might research for each part of their model that would help them improve their understanding of sound and write them in their notebooks.

2. When students are done, give each one a chart marker and have them rotate through the three prepared chart papers (SS, SB, SD). On each, they should write their question for that part of the model and initial next to it. If someone else already added the same question, just initial next to it. *Students should talk about their questions with their classmates while they are waiting for their turn at a chart paper.*

3. Once all students have their questions on the charts, give them five minutes to do a gallery walk. They should take their notebooks with them and write down any new questions that have several initials next to them.

Today, we will start with the source of sound. Give students a minute to find the questions they wrote down (initially and after the gallery walk) about the source of sound and star them in their notebooks; while they are working, move the **Sound Source** (**SS**) chart to the front of the room. Then as a class, discuss the questions that were on the SS chart about the source of sound, beginning with the ones that had the most initials. For each question, discuss whether answering the question will help us figure out the phenomenon. If the class reaches consensus that a question is relevant, put a star by it.

Resources and Strategies

Self-Assessment

Part 2. Investigation: What can observations of tuning forks tell us about what produces sound?

Materials: Computer, Projector, Task Card 2, Tuning Forks, Rulers, Thumpr	
Student Practices	• Investigate the sources of sound
Instructions	*DRIVING QUESTION: What can observations of tuning forks tell us about what produces (causes) sound?* 1. Let students know that we can start investigating what causes sound by making some observations. Arrange students into groups of 4-5, and pass out a data table for observations and a Lesson 2 Task Card, *What's that Tune?* (1 per student). Give students a couple of minutes to read the task card, then put up **Slide 3.** Ask if anyone has any clarifying questions after reading the task card and remind students that they should always **only** tap a tuning fork on the thumper; it could damage the tuning fork otherwise. *2.* Pass out a tuning fork and a ruler to each student. Before students start, they should measure the length (cm) of their tuning fork and note the number and letter stamped on it, writing the information in the first two rows of the table. Each student will work individually with one tuning fork, making the observations listed on the task card, and recording what they observe in the first column of the table. *3.* When everyone at the table is finished with their tuning fork, pass it counterclockwise to the next student and repeat the activity. *4.* Continue passing counterclockwise until everyone has observed with four tuning forks. *5.* Put up **Slide 4** which defines the word **pitch** and ask if students have any clarifying questions. Then give them time to answer the two reflections questions at the bottom of the data table. Then they should turn and share with a nearby partner. Ask a few groups to share the correlations they noticed.
Resources and Strategies	Think-Pair-Share
Part 3. How can we use technology to enhance our observations of tuning forks and other vibrating objects?	
Student Practices	• Construct Explanations
Instructions	*DRIVING QUESTION: How can we use technology to enhance our observations Of tuning forks and other vibrating objects?* 1. Ask students to consider the first two observations they made, when they used their senses of touch and hearing before and after tapping the tuning fork on the thumper. What did they feel/hear before tapping? *Nothing.* After tapping? *They heard a sound and felt a tingle.* What happened at the point they tapped the tuning fork to cause this change? Ask them to make a drawing in their notebook of what might have happened at the point of **impact** and write an explanation.

2. While students are working, walk around the room and quietly ask probing questions if students are struggling. Suggested prompts:
    1. What would you expect to see if you looked closely while the tuning fork hit the thumper? *The impact caused the tuning fork to vibrate.*
    2. What might be happening during the collision to cause the change in the tuning fork? *Kinetic energy is transferred to the tuning fork.*
    3. What might be happening to the thumper during the collision? *The kinetic energy from the moving tuning fork 'bounces' off the rubber and back into the tuning fork, causing it to vibrate.*
3. After students have finished, have them turn to their partner and share their ideas for what is happening when the tuning fork is tapped on the thumper. Then ask groups to share one idea and write them on the whiteboard. Students might use the words 'vibrate' or '**vibration**'. Challenge them to describe in their own words what they mean when they use that science term.

4. Put up **Slide 5** with some prompts for students to think about while you are passing out the Lesson 2 graphic organizer for *Scale, Proportion and Quantity.* What scale is most appropriate to consider for the phenomenon of a tuning fork producing sound? Put up **Slide 6** and have students look at the options in the first column (Step 2) of the graphic organizer. Which one seems most relevant? Have students think quietly for a minute, then share their choice and reasoning with a partner. Then poll students by having them raise the number of fingers of the choice they made. Pick a student who chose each option (if applicable) to share their reasoning. Let them know that all of their reasoning is valid, and we will be exploring some of the other concepts later in the unit, but today we will be looking at **time scale**.

5. Next have students look at the next column over (Step 3) labeled *representation*. There are three time scales shown, molecular, biological and geological (evolutionary). Answer any clarifying questions about what we mean by those three time scales (fast, slower, slowest), then students should check the one they think is relevant for the tuning fork. *They should be thinking about the fastest time scale (molecular).* Ask for ideas about how we can see things that are on a very fast time scale; does anyone know of any technologies that can be used for this? *Slow Motion Video*

6. **Slide 7** gives a summary of the technology behind slow motion video. After looking at the ratio, click it again to ask students the question*, Is x100 enough so that we can see a tuning fork move?* Ask them what they think, then move to **Slide 8.** Have students think about the prompts and write their observations as you play the slow-motion video of the tuning fork as it is hit with a mallet. Play the video through 2-3 times until students are finished.

7. All of the students should have noticed that the tines of the tuning fork were vibrating. Ask everyone to think to themselves: Which directions were the tines vibrating? Then have them hold up two fingers to represent the

	two tines and move them in the direction of vibration. *In towards each other and out away from each other* 8. Give students time to answer the two questions on Step 4 of the graphic organizer, then tape or paste it into their notebook. Then they can change or add to the drawing and explanation they made at the beginning of this section based on the slow motion video. 9. Why did the different tuning forks sound differently? Put up **Slide 9.** Which tuning fork had the lowest pitch? *256* Highest pitch? *512.* Hold those two tuning forks up to the class and ask them which one they think would be easiest to start vibrating. *The smallest, lightest one (512).* The slide defines two quantities that describe vibration, **frequency** (vibrations / second) and **period** (time / vibration). The unit of frequency, ƒ, is called a **Hertz (Hz).** A period is 1/ƒ. to think about other examples of things that seem to produce sound through vibration. The frequency of each tuning fork is the stamped number. The higher the frequency, the higher the pitch. The frequencies and periods are given in a table on the slide. 10. **(Slide 10)** Ask students to think about other objects that make sound which might be caused by a vibration. They should write down three and share their ideas with their partner. They will probably have some musical instruments in their list. Ask the students how many of them had listed a guitar, then play the video on **Slide 11.** Have students write down what they notice and wonder as they watch the guitar strings in slow motion. What differences do they notice between how the strings respond? 11. (Lesson Formative Assessment) **(Slide 12)** Ask students to reflect on the similarities and differences between the different guitar strings and different sizes of tuning forks. Their reflections should include the four terms introduced in this lesson: vibration, pitch, frequency and period. (Optional) If time, play the video on **Slide 13**. How many different vibrations are shown in the video? In class, or as homework, have students pick one example from the video and write an explanation for how that object makes a sound caused by a vibration. The video is also available on YouTube at https://www.youtube.com/watch?v=W4s2UwKm7dc.
Resources and Strategies	Think-Pair-Share *✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY** Help students think about what they could change to see more about what is happening with the objects. Posing questions about what the limits are of our observations can help them think about how changing the scale (in this case a slower scale) will help them see more.
Science Terminology and Concepts	**Source –** A source is the place or thing from which something comes from or starts at, or the cause of something. **Detector –** A detector in science is a device for discovering or observing the presence or existence of something.

	Tuning Fork - A tuning fork is a two-pronged fork with the prongs formed from a U-shaped bar of elastic metal. Depending on the length of the fork, it vibrates at a particular pitch, or frequency. A tuning fork is used to tune musical instruments. **Vibration (v. vibrate)** – Vibration or oscillation means quick moving back and forth (or up and down) about a point of equilibrium. **Pitch –** Pitch is the highness or lowness of a sound. **Frequency –** Frequency is the number of cycles per second in a vibration. The unit of vibration is Hertz (Hz) or 1/seconds. **Period –**number of cycles of a pattern per unit time. Frequency is a measurement of Period.

Sound and Light

Lesson 2 Data Table

Record your observations:

	Tuning Fork 1	Tuning Fork 2	Tuning Fork 3	Tuning Fork 4
Length in cm				
Stamped # & letter				
A. What do you feel (before thumping)?				
B. What do you hear (before thumping)?				
C. What do you feel (after thumping)?				
D. What do you hear (after thumping)?				
E. What do you hear when you rotate it?				
F. What do you hear/feel when you hold the end to the bone behind your ear?				
G. What happens if you hold the tines to the surface of the water?				

- Based on your observations, rank the tuning forks from the one with the lowest pitch to the one with the highest pitch:

Lowest __________ Next Lowest ________ Next Highest ________ Highest ___________

- What patterns (correlations) do you notice between the pitch of a tuning fork and your other observations or measurements? Write at least two correlations in your notebook.

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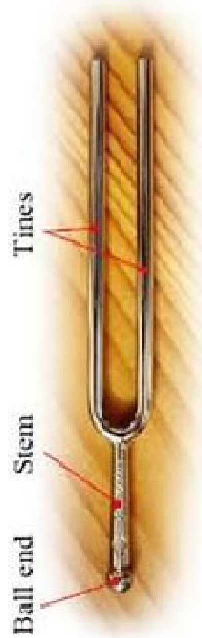
Task Card - Lesson 2
What's that Tune?

Parts of a tuning fork:



Using a tuning fork:

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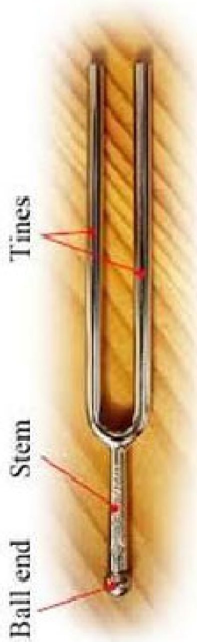
Task Card - Lesson 2
What's that Tune?

Parts of a tuning fork:



Using a tuning fork:

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Task Card - Lesson 2
What's that Tune?

DRIVING QUESTION. What can observations of tuning forks tell us about the source of sound?

MATERIALS: *Tuning forks, thumper, ruler*

IMPORTANT: Follow the rules your teacher gives you for using tuning forks. See diagram on back.

1. Record the length of the fork and the labels on it.
2. With your tuning fork try the following:.

Before touching the tuning fork to the thumper:

A. Gently touch a finger to a tine of the fork. What do you feel?
B. Hold it to your ear (about 5-6 inches away). What do you hear?

Tap the thumper between each of the following observations:

C. Gently touch a finger to a tine of the fork. What do you feel?
D. Hold it to your ear (about 5-6 inches away). What do you hear?
E. Hold it to your ear (about 5-6 inches away) and slowly rotate the handle. What do you hear?
F. Touch the ball end of the tuning fork to the bone right behind your ear. What do you hear or feel?
G. Touch the tines to the surface of the water. What happens?

3. Repeat 1 & 2 with three other tuning forks.

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Task Card - Lesson 2
What's that Tune?

DRIVING QUESTION. What can observations of tuning forks tell us about the source of sound?

MATERIALS: Tuning forks, thumper, ruler

IMPORTANT: Follow the rules your teacher gives you for using tuning forks. See diagram on back.

1. Record the length of the fork and the labels on it.
2. With your tuning fork try the following:.

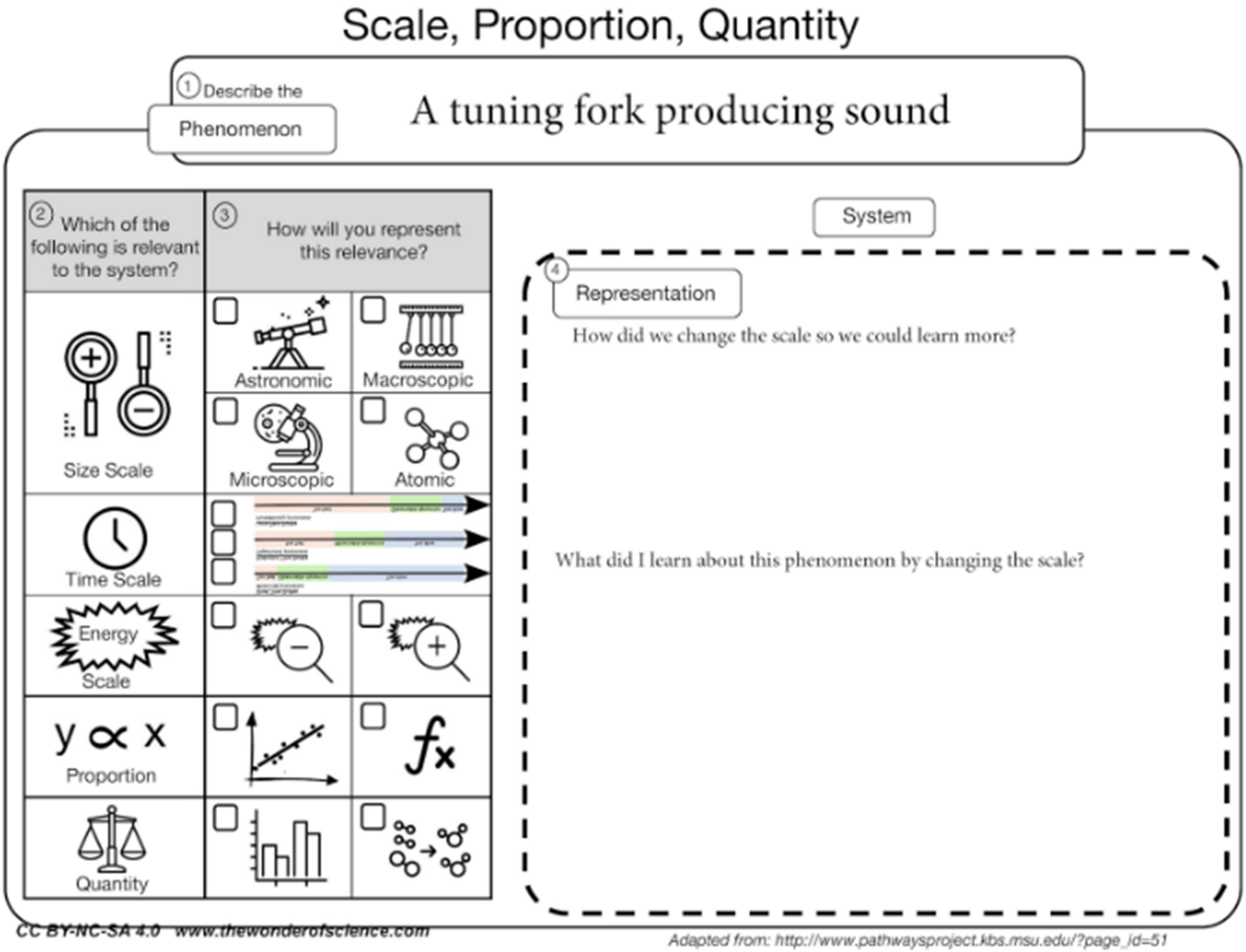
Before touching the tuning fork to the thumper:

A. Gently touch a finger to a tine of the fork. What do you feel?
B. Hold it to your ear (about 5-6 inches away). What do you hear?

Tap the thumper between each of the following observations:

C. Gently touch a finger to a tine of the fork. What do you feel?
D. Hold it to your ear (about 5-6 inches away). What do you hear?
E. Hold it to your ear (about 5-6 inches away) and slowly rotate the handle. What do you hear?
F. Touch the ball end of the tuning fork to the bone right behind your ear. What do you hear or feel?
G. Touch the tines to the surface of the water. What happens?

3. Repeat 1 & 2 with three other tuning forks.


Scale, Proportion, Quantity
1 Describe the
Phenomenon
A tuning fork producing sound
2 Which of the following is relevant to the system?
3 How will you represent this relevance?
Size Scale
Astronomic
Macroscopic
Microscopic
Atomic
Time Scale
Energy Scale
y ∝ x
Proportion
Quantity
System
4 Representation
How did we change the scale so we could learn more?
What did I learn about this phenomenon by changing the scale?
CC BY-NC-SA 4.0 www.thewonderofscience.com
Adapted from: http://www.pathwaysproject.kbs.msu.edu/?page_id=51

Lesson 3	An Impactful Event
Overview Standard(s) & Objectives	**Overview** How does energy transfer in a vibrating system? Students explore further how the impact causes a vibration and how the energy is transferred into the surrounding air in the form of a wave. **Building Toward** **MS-PS3-5** Crosscutting Concept/SEPs • Develop Models • Conduct Investigations • Using Mathematical Representations **Where We Are Going** In Lesson 2, students used tuning forks to explore the production of sound, observing the effects of the tuning fork in the classroom and through a slow motion video. They used this to develop a model of vibration in the tuning fork causing sound, with the vibration caused by energy transfer from the impact of the tuning fork on the thumper. In Lesson 3, students will figure out that sound is always caused by energy transfer into the surrounding air molecules which is then transmitted. The source of the sound may be something that vibrates easily and for a long time, such as the tuning fork, or something that is rigid enough that it does not vibrate for long, such as a pen tapped on a desk. We distinguish the second case as being an 'impact sound'. An impact sound would cause a pulse of energy whereas a vibration over a longer time would cause a wave of energy. Students will investigate compression pulses and waves moving through a spring as a model for sound waves and develop mathematical representations for the displacement of coils (movement of air molecules) as a function of amplitude (for a pulse or wave) and frequency (for a wave). They will relate that displacement to the amount of energy in the system.
Materials	Per Student: • Science Notebook • Masking Tape • Lesson 3 Data Sheet (print master) Per Group (4-5 Students) Part A: • Task Card 3, Part A • Tuning Forks (4-5) • Ping-Pong Balls on String (2) • Thumper • Plastic Ruler (2) Per Group (3-4 Students): • Energy Transfer Apparatus: ▪ Wooden Block

<table>
<tr><td></td><td>

Duct Tape
Clamp
Meter Sticks (2 – teacher provided)
Marker
Marbles

Per Classroom:

Computer, Projector
PowerPoint

</td></tr>
<tr><td>Preparation</td><td>

Material Preparation

- Tape the plastic rulers to the edge of the wooden blocks with duct tape so that when the block is laid on a table, it will just clear the top of a meter stick. (See picture).

- Secure the wooden block to the table so that it doesn’t move when you pull back and release the attached ruler. You can do this by taping the block to the table with duct tape or using a C-clamp.

- Place 2 wooden metersticks parallel to each other with a 1.9 cm gap between them. Slide them under the loose end of the plastic ruler so that the ruler is lined up over the 10 cm mark on each ruler.

- Make sure the marker and marbles can slide between the two metersticks without getting stuck. Adjust the space between the metersticks if needed. Duct tape the ends of each meterstick to the table.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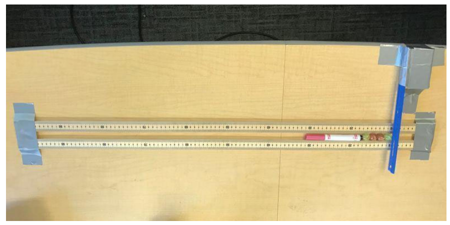
- Repeat this process to build one apparatus for every group of 3-4 students.
- Watch the videos for the frequency vs. energy investigation and the video for the amplitude vs. energy investigation (on unit Flash drive (Videos 9&10)). Test the two investigations students will do with this apparatus. If for some reason your students cannot conduct the investigation themselves or students are absent, you can show them the videos for each investigation.



This activity, photographs and videos are from OpenSciEd.com unit on Waves.
</td></tr>
<tr><td colspan="2">

Part 1. What factors determine how much energy a vibrating system has and how can we measure it?
Materials: Computer, Projector, PowerPoint
</td></tr>
<tr><td>Student Practices</td><td>

- **Extend models from a tuning for to all sources of sound**
</td></tr>
<tr><td>Instructions</td><td>

DRIVING QUESTION: What factors determine how much energy a vibrating system has and how can we measure it?

1. Remind students that we ended the last lesson by watching a slow-motion video of various objects vibrating and causing different sounds. In our end of lesson reflections, we noted some differences and similarities between slow motion videos of a set of guitar strings being plucked and the tuning forks we explored. Have students turn to those reflections and call on 3-4 students randomly to read one of the similarities they noticed, then 3-4 students to read one of the differences they noticed. Record any correlations they noticed on the board (*e.g., thickness of string and size of tuning fork with pitch or frequency of vibration*).
2. What might cause these differences? Have students flip to the page of their notebook where they wrote their observations about the original slow-motion video of the tuning fork, and review what they noticed about the interaction of the mallet and the tuning fork. Call on another three students randomly to read one of their observations. They might use the terms energy, force, or impact to describe what happens and why the tuning fork starts vibrating. These are all fine.
3. Digging a little deeper into the interaction of the tuning fork with the mallet or the thumper, put up **Slide 1** and have students write their ideas about where the energy is in the system in the three 'before
</td></tr>
</table>

	impact' cases, and the two 'after impact' cases. Discuss the five cases, again calling on random students to give their ideas. 4. How do we know that the vibrating tuning fork has energy? Have students look back at their Lesson 2 data table. What observations did they make in Lesson 2 that could be evidence that the tuning fork has energy? Have students do a Think-Pair-Share. They are likely to choose the splashing water as their example but some of the other observations could be used as evidence as well. Ask students to think about the splashing water example and discuss with their partner the observations they made in Lesson 2 when they touched the tuning fork to water. Which tuning fork splashed the most? Have enough groups report out to ensure there is a class consensus that the xxx fork splashed the most water. 5. Today we will be working in groups to conduct two different investigations to learn more about energy and energy transfer in a system. Let students know that it is important to be respectful when working in groups. Pass out a copy of the Groupwork Norms (a Word file is on the flash drive and can be modified as a teacher wishes). Give students a chance to tape them into their notebook, then discuss each one, making sure everyone understands them. Put up **Slide 3** which describes how to have a dyad discussion. Have students turn to face a partner and have a dyad discussion for the question: *Which norm will be the biggest challenge for me to follow, and why?* 6. Move students into groups of 4-5 (use the same groups as in Lesson 2 if feasible) and pass out tuning forks, (one per student), task card, ping-pong balls on strings, and rulers (two each per group), and one thumper per table. Give each table a couple of small pieces of masking tape and have them tape a ping-pong ball onto each side of the table, hanging down to almost touch the ground. Each group will split into two for measuring but work together to develop a procedure for the investigation, share the data and do the analysis and graphing. 7. Put up **Slide 4** with prompts for groups to report out to the rest of the class. *The purpose of this report out is for students to come to a class consensus as to what the results should be before moving on.* Give groups a couple of minutes to discuss their answers to the prompts and pick a spokesperson. Then have each group report out their results. *8.* Ask students to interpret the data individually by drawing a model and writing explanation in their notebooks using the prompts on **Slide 5**. Students will have the chance to share and refine their models after the next investigation. 9. **Slide 6** shows a slow-motion video of a tuning fork superimposed on a ruler. The scientific term **amplitude is** defined by the distance the tine of a tuning fork moves during each vibration.

<table>
<tr><td>Resources and Teaching Strategies</td><td>NO HANDS-UP, EXCEPT TO ASK A QUESTION

Research shows that if teachers ask students to raise their hands to answer a question, they are relying on the same few, confident students every time and are most likely not getting the true pulse of the classroom. There are many strategies for randomizing discussions. For more information, see Dylan Wiliams & Siobhan Leahy, Embedding Formative Assessment, pgs 64-70, or Amanda Eastman, http://www.barkerinstitute.com.au/media/2623/the-controversial-classroom-making-understanding-visible-with-no-hands-up-print.pdf

Groupwork - Dyad
Students will be doing several graphing exercises over the course of the unit. These could be done by hand, with Desmos, Excel or Google Sheets among other options. We suggest Google Sheets for exercises in which students are generating classroom sets of data.</td></tr>
<tr><td colspan="2">Part 2. How can we gather more evidence about how a vibrating system transfers energy?
Materials: Computer, Projector, Task Card 3-3, Plastic Ruler, Wooden Block, Duct Tape, Meter Sticks (2/group), Marker</td></tr>
<tr><td>Student Practices</td><td>• Investigate energy transfer in waves</td></tr>
<tr><td>Instructions</td><td>DRIVING QUESTION: How can we gather more evidence about how a vibrating system transfers energy?

1. We are going to work in groups again to do another investigation on energy transfer. This time, there should be a max of 4 students per group, so rearrange as necessary into groups of 3-4. (Each group should have one copy of the Lesson 3 Task Card.) Pass out a data sheet to each student. Then direct them to gather around one of the apparatuses that were built in advance and demonstrate how to pull back the ruler and use the energy transfer to move a marble and marker.

a. Ask for suggestions about how to change the amplitude. Students should suggest pulling the ruler back different amounts.

b. Ask for suggestions about how to change the frequency. (how many times the ruler strikes the marbles) When they suggest pulling it back multiple times, try it. It won’t work because the first marble doesn’t return to the starting point.

c. Show students how to simulate more than one compression wave by placing the first marble against the ruler again, pulling back the ruler, and launching it again without moving the marker from where it came to rest the time before. Tell students that to simulate the production of three compression waves, we have to repeat it yet another time, allowing the marker to be pushed farther and farther with each wave.

2. Then each group will move to their own apparatus and follow the instructions on the Task Card. Once they have collected the data, they can use the graph paper in the Print master, or the online graphing calculator, DESMOS (www.desmos.com) to make plots of the distance the marker travels (y-axis) as a function of the amplitude or frequency (x-axis).</td></tr>
</table>

	3. (Lesson Formative Assessment) Once their graphs are complete, students should pick one of the competing claims on **Slide 7** and give their evidence and reasoning for which they chose. This is the assessment for this lesson. 4. Once students finish their assessment, give them a chance to refine their model of energy in the vibrating system based on their newest investigation. If time permits, share with a partner.
Science Concepts and Vocabulary	**Amplitude –** The amplitude is the maximum displacement of the particles of the medium as a pulse or wave moves through. **Frequency –** The frequency of a wave refers to how often the particles vibrate when a wave passes through a medium. The unit of frequency is # of vibrations / unit time.

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Task Card - Lesson 3
Energy Transfer, Part A

DRIVING QUESTION. How much energy can be transferred from a vibrating tuning fork and how does it vary with frequency?

MATERIALS: *Tuning forks, ping-pong ball on string, ruler, thumper*

1. Thump the tuning fork and carefully move the vibrating end to the ping-pong ball. Everyone in your subgroup try it and then write down your notices and wonders.
2. Does it make a difference how the tuning fork is tapped on the thumper? Try it and see.
3. Compare notes with the others at your table. .Decide with your full group how to tap the tuning fork, and how to use a ruler to measure how much the ping-pong ball moves. Make a data table then each person measure with their tuning fork. Take three measurements.
4. Average your measurements and then share the results with your group. Make a graph in your notebook of the movement of the ping-pong ball as a function of frequency.

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Task Card - Lesson 3
Energy Transfer, Part A

DRIVING QUESTION. How much energy can be transferred from a vibrating tuning fork and how does it vary with frequency?

MATERIALS: *Tuning forks, ping-pong ball on string, ruler, thumper*

1. Thump the tuning fork and carefully move the vibrating end to the ping-pong ball. Everyone in your subgroup try it and then write down your notices and wonders.
2. Does it make a difference how the tuning fork is tapped on the thumper? Try it and see.
3. Compare notes with the others at your table. .Decide with your full group how to tap the tuning fork, and how to use a ruler to measure how much the ping-pong ball moves. Make a data table then each person measure with their tuning fork. Take three measurements.
4. Average your measurements and then share the results with your group. Make a graph in your notebook of the movement of the ping-pong ball as a function of frequency.

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Task Card - Lesson 3
Energy Transfer, Part B

DRIVING QUESTION. How can we determine whether higher amplitude or frequency of a vibrating system transfers more energy?

MATERIALS: *Energy transfer apparatus with one marker and several marbles, data table, safety goggles*

SAFETY: *Wear safety goggles while investigating.*

1. Watch your teacher demonstrate how to use the apparatus.
2. Plan your roles. You will need one person to make sure the base of the ruler stays in place and to hold it in place if it is slipping, another person to make sure the first marble is lined up against the ruler as it is pulled back, and a third person to pull the ruler back. If you have a fourth person, they can record data for your group. Rotate roles between trials.
3. Plan your amplitude investigation. How will you vary the amplitude? Take measurements at a minimum of 8 amplitudes (3 trials each).
4. Plan your frequency investigation. How will you vary the frequency? What amplitude will you use for your trials? Take measurements at a minimum of 5 frequencies (3 trials each).
5. Everyone should complete the data table and paste or tape in notebook.

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Task Card - Lesson 3
Energy Transfer, Part B

DRIVING QUESTION. How can we determine whether higher amplitude or frequency of a vibrating system transfers more energy?

MATERIALS: *Energy transfer apparatus with one marker and several marbles, data table, safety goggles*

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1. Watch your teacher demonstrate how to use the apparatus.
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3. Plan your amplitude investigation. How will you vary the amplitude? Take measurements at a minimum of 8 amplitudes (3 trials each).
4. Plan your frequency investigation. How will you vary the frequency? What amplitude will you use for your trials? Take measurements at a minimum of 5 frequencies (3 trials each).
5. Everyone should complete the data table and paste or tape in notebook.

DATA SHEET – LESSON 3, PART B

PART A. Amplitude Measurement

	Distance Marker Moved			
Amplitude	Trial 1	Trial 2	Trial 3	Average

PART B. Frequency Measurement.

Amplitude used for all frequency measurements: ______________________

	Total Distance Marker Moved			
Frequency	Trial 1	Trial 2	Trial 3	Average

<table>
<tr><th>Lesson 4</th><th>Feeling the Pressure</th></tr>
<tr><td>Overview Standard(s) & Objectives</td><td>Overview
How does the energy of a vibrating system become sound?

We explore how vibrational energy can transfer energy into the surrounding air in the form of a pulse wave or periodic wave. Then we plan and conduct investigations using a compression pulse or periodic wave in a spring as an analogy to a sound wave. We determine mathematical representations for displacement of a wave.

Building Toward
MS-PS3-5
Crosscutting Concept/SEPs
Develop Models
Conduct Investigations
Where We Are Going
In Lesson 2, students used tuning forks to explore the production of sound, observing the effects of the tuning fork in the classroom and through a slow-motion video. They used this to develop a model of vibration in the tuning fork causing sound, with the vibration caused by energy transfer from the impact of the tuning fork on the thumper.

In Lesson 3, students will figure out that sound is always caused by energy transfer into the surrounding air molecules which is then transmitted. The source of the sound may be something that vibrates easily and for a long time, such as the tuning fork, or something that is rigid enough that it does not vibrate for long, such as a pen tapped on a desk. We distinguish the second case as being an ‘impact sound’. An impact sound would cause a pulse of energy whereas a vibration over a longer time would cause a wave of energy.

Students will investigate compression pulses and waves moving through a spring as a model for sound waves and develop mathematical representations for the displacement of coils (movement of air molecules) as a function of amplitude (for a pulse or wave) and frequency (for a wave). They will relate that displacement to the amount of energy in the system.</td></tr>
<tr><td>Materials</td><td>Per Student:
Science Notebook
Safety Glasses (teacher provided)
Per Group (4 Students) :
Lesson 4 Task Card
Talking Stick
Lesson 3 Material Bag:
Slinky spring
Meter Tape
Roll of masking tape
Rulers (2)
Markers (2)</td></tr>
</table>

	▪ Yarn • Timer • Graph Paper (print master) Per Classroom: • Computer, Projector • PowerPoint
Assessment Opportunities	**Modeling:** Students' notebooks should reflect that they understand that sound can be made either by a vibration or an impulse and they should have attempted to model the similarities and differences between the two. **Planning Investigations:** Students have answered all three reflection questions. Students have collaborated on planning the investigation and written procedure in their notebook. **Investigating:** Observe that all students are engaged with their groups during the investigation and have copied all the data and analysis into their notebooks.
Part 1. How does a vibrating object cause sound? **Materials: Computer, Projector, PowerPoint, Plastic Bottle, Craft Stick, Small Bell, Tape**	
Student Practices	• Exploration and Observation
Instructions	*DRIVING QUESTION: How does a vibrating object cause sound?* 1. Remind students that in Lesson 2, we showed evidence that a vibrating tuning fork had energy because it splashed when we touched the surface of water. Tell them that we are going look at that phenomenon in more detail using the slow-motion video technique. This time, while watching, students should focus on what is happening to the water rather than the tuning fork itself and write down their observations and wonders. Show the video (**Slide 1)** and give students a chance to take notes, then reflect on the questions in the prompts. Then have them share with a nearby partner and have a few people report out. *Students should notice that in addition to splashing droplets, a periodic wave is formed at what appears to be the same frequency as the vibration.* Ask students to speculate what is causing the water wave. *They should have some observations/ideas about how when the tines move apart, they are pushing the water away.* 2. Put up **Slide 2** and have students reflect individually. What happens to the energy of a vibrating tuning fork in air? Students should write down some ideas and then share again with their partner. Have a few groups share out with the class. *Students should reason that the vibrating tuning forks push air molecules in analogy to the water video.* 3. **Slide 3** shows a diagram and an animation of how a tuning fork causes the air to change around it and sets up a **pressure wave** moving through a **medium** (air in this case)**.** The pressure wave consists of **compression** regions – where the air particles are close together – and **rarefaction**

	regions – where the air particles are far apart. Give students an opportunity to draw this in their notebooks and label the regions of the wave. 4. Do sound waves move through water? Give students a moment to think about it and then vote – fist for no, five fingers for yes. Pick a few people to explain why they voted the way they did. *Students most likely have experience with hearing things underwater.* Go to **Slide 4** and replay the slow-motion video of the tuning fork in water. Stop it once the wave is moving through the water and ask the students to point out where compression and rarefaction regions are in this water wave. Then tell the students you are going to play a second short video and they should note any similarities and differences they notice in their notebooks. Then play the video of the rock tossed into the water. Pick a few students at random to note the similarities and differences. Once students have reported out, click the slide once more. *In both cases, energy is transferred into the water and radiates outward in the form of a wave. In the first case, the source of the wave is a periodic and it creates a periodic wave. In the second case, the source is a one-time impulse, and it creates a pulse wave.* 5. Can we get this second kind of pressure wave in air? Give students a couple of minutes to think about it and then talk over their ideas with the same partner. Randomly call on a few students to share with the class. Then tap a rigid object on the desk or another rigid object to make a sharp noise (or make a hand clap). Have students think and write an explanation for how the new sound was made in their notebook. Make a drawing, including both objects and the surrounding air and label the energy flow in the system. 6. Is a clap of thunder closer to a sound made by a vibrating object, such as a tuning fork, or a sound made by an **impact**, like a hand clap? Think about it and talk it over with your partner. Then poll the class; ask a few students from each side to give their reasoning. *Students could go either way on this since sometimes thunder is long and rumbling.* 7. Ask students to make a Notices and Wonders t-chart in their notebook. Show Video #12 (linked from **Slide 5**) of how thunder is formed. As students watch the video, they should think about the question of thunder (vibration or impact) and write down any other notices and wonders they have. Let them know that we will be coming back to thunder in more detail after we do some investigations to figure out more information about sound waves.
Resources and Teaching Strategies	Think-Pair-Share
Part 2. How can we model the production and transmission of sound using a spring? **Materials: Task Card 4 (A), Talking Stick, Computer, Projector, PowerPoint**	
Student Practices	• Creating a model and sharing ideas

Instructions	*DRIVING QUESTION: How can we model the production and transmission of sound using a spring?* 1. Put up **Slide 6** and fill in the Analogy Table together using student suggestions. *The source of a sound wave could be anything talked about in the last few lessons. The source of the spring wave (in this case) is a hand. The medium that is displaced as the wave moves through is air or water (for sound) or the coils of the spring.* Then ask students to write down suggestions of how they would make a periodic wave or a pulse wave using the spring and their hand. 2. **Slide 7** describes how the terms amplitude and frequency are used in characterizing waves (an extension from vibrating objects). Have students flip back to the data they took in Lesson 2 measuring energy transfer as a function of amplitude and frequency. Based on that data, make a prediction (**Slide 8)**: will amplitude or frequency have a bigger effect on the properties of a sound wave? A compression wave in a spring? 3. Assign groups of four (minimum) or five for the next set of investigations. Using a talking stick rotate around the group, with each person in turn sharing their ideas of how to make a periodic wave or a pulse wave using the metal slinky spring and their hand. After everyone has had a chance to contribute, give them a chance to come to a group consensus on how they can model sound moving through air with a spring? How will they distinguish between a pulse wave (made with an impact) and a periodic wave (made with a vibration)? Rotate through the tables and pass out Task Card 4 while students are talking. Part A prepares the students for the modeling activities in Part B. 4. Before students get into full planning of their investigation, put up **Slide 9,** which defines some science terminology for waves. As they are working on a procedure for their investigation, they should try to incorporate some of the terminology. Remind students about the need to treat the springs with respect. Show video #13(linked from **Slide 9**) which shows how to generate a compression wave with the spring. (Emphasize that this is one way that will not damage the spring; if they thought of a different way, they could try it, but be sure it is really a compression, or longitudinal, wave.) *5.* Once the group has reached consensus about how they will generate their waves, everyone should agree upon and write down a procedure in preparation for the investigation in Part B. The procedure should include: a. Sometimes you will be asked to generate a pulse wave and sometimes a periodic wave. How will you generate each? b. As your group members take turns in being the wave generator, how will you vary the <u>amplitude</u> of the pulse or wave in a consistent way? c. As your group members take turns in being the wave generator, how will you vary the <u>frequency</u> of the wave in a consistent way? *Remind students that they should try to use some of the scientific terminology they have been introduced to in writing down their procedure.*

Resources and Teaching Strategies	ATTENTION TO EQUITY: A talking stick or talking chips gives everyone in the group a chance to talk and a chance to listen
Part 3. How do the properties of compression waves in springs vary with amplitude and frequency? **Materials: Task Card 4, Lesson 4 Material Bag, Timer, Safety Glasses, Graph Paper**	
Student Practices	• Investigate Wave Properties
Instructions	*DRIVING QUESTION: How do the properties of compression waves in springs vary with amplitude and frequency?* 1. Check that each group has a completed procedure, then have students turn the task card over and read **Part B** together. The task card assigns four procedural roles for the modeling investigation with lots of rotation so that everyone does each role multiple times. If there are five students in the group, add a third observer into the rotation. 2. Remind students to note the places where they should stop and write observations or analyze data before continuing. Once they understand what they are doing, give a Lesson 4 Materials bag (spring, meter tape, roll of masking tape, rulers (2), short piece of yarn, markers (2)) and a timer to each group and assign them a table or spot on the floor where they can stretch the spring to 2 meters and lay out tape to take their measurements (see diagram on task card). *TEACHER NOTES: Carpeted floors do not work well for spring investigations. It is highly recommended that all students wear safety glasses or goggles when working with the springs.* If time permits, while students are analyzing their final data, pass out two sheets of graph paper to each group. Each group will make two graphs: displacement as a function of amplitude and displacement as a function of frequency. *This could also be done at the beginning of Lesson 5. We will interpret the results from these graphs then.*
Science Concepts and Vocabulary	**Wave –** A wave is a repeating movement up and down or back and forth. **Pulse wave –** A pulse wave is a short burst of energy that moves through a medium. **Periodic wave** – A periodic wave is a repeating transfer of energy through a medium. **Propagation (v. propate) –** Propagation is the process of a disturbance such as a wave moving through a medium. **Medium** – A medium is the substance or material that carries a wave. **Mechanical wave –** A mechanical wave is a wave that propagates as a vibration of matter, therefore transferring energy through a medium. **Pressure wave –** A pressure wave is a wave in which the propagated disturbance is a change in pressure of a material medium.

	Longitudinal wave –Longitudinal waves are waves in which the displacement of the medium is in the same direction as, or the opposite direction to, the direction of propagation of the wave. **Compression region –** Compression regions in longitudinal waves are the regions where the particles of the medium are pushed close together. **Rarefaction regions –** Rarefaction regions in longitudinal waves are the regions where the particles of the medium are pulled farther apart. **Displacement –** The displacement is the distance that the particles of the medium move from their equilibrium (rest) position as the disturbance propagates through the medium.

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Task Card - Lesson 4
SPRING INTO ACTION
PART A - PREPARE

DRIVING QUESTION. How can we use a spring as a model for a sound wave? What are some measurable properties of a mechanical compression wave?

MATERIALS: talking stick

1. With your group, use a talking stick to hear everyone's ideas for generating a compression wave with the spring. Can the group come to consensus on a way to do it?
2. Your teacher will show you a video with one way that works to generate a compression wave without damaging the spring. Sometimes you will be asked to generate a pulse and sometimes a vibration. Discuss the difference with your group.
3. As your group members take turns in being the wave generator, how will you vary the amplitude of the pulse or wave in a consistent way?
4. As your group members take turns in being the wave generator, how will you vary the frequency of the wave in a consistent way?

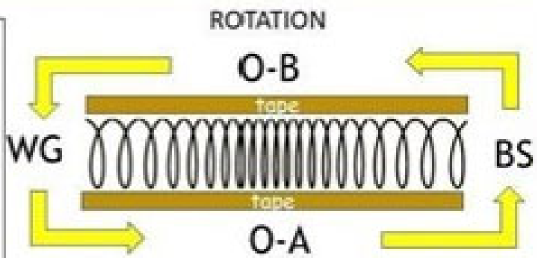
GROUP ROLES (rotates with each measurement or observation):

- WAVE GENERATOR (WG) - the energy source for the pulse or vibration
- BACKSTOP (BS) - holds the other end of the spring fixed in position; also will record data after each set of observations.
- OBSERVER A (O-A) - makes observations or measurement
- OBSERVER B (O-B) - makes observations or measurement

- Wear safety glasses when working with the spring.
- Always keep the spring on the table or floor.
- Only make compression waves.
- Treat it with respect: it is not a toy!

IMPORTANT

TO GET STARTED: Use a table or the floor. Stretch out the spring to about 4 meters. Lay two rows of tape along the spring one on each side and mark the two ends of the stretched spring on the tape. Start each measurement at those same points.



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Task Card - Lesson 4
SPRING INTO ACTION
PART B - EXPLORE

- BASICS -

A. WG send one energy pulse down the spring. O-A watch for compression region(s). O-B, watch for rarification region(s). What happens when the pulse reaches the BS? Try it a few times.

B. Rotate positions and repeat A. Everyone discuss what you observed and make notes in your notebooks.

C. Tie a piece of yarn to a coil near the center of the spring. Mark the equilibrium point on both sides of the tape. WG send a pulse down the spring. O-A, mark how far the yarn moves forward. O-B, mark how far the yarn moves backward. Repeat two more times.

D. Rotate and repeat C. When finished, measure each mark from the equilibrium position of the yarn (the displacement) and average the forward and backward measurements. BS record the data. Are they the same? Why or why not?

- AMPLITUDE -

E. Decide on three different amplitudes to measure and mark the position on the tape. Give the WG practice in stretching the spring to reach each mark with a sharp pulse. Then do three data runs at each amplitude, following the procedure of C above.

F. Rotate and repeat E. When finished, measure each mark from the equilibrium position of the yarn and average the forward and backward displacements for each amplitude. BS record the data. Did they change? Why or why not?

- FREQUENCY -

G. How can you vary the frequency of the wave? Talk it over with your group. Pick three different frequencies and send ten energy pulses down the spring, taking care to keep a constant amplitude . O-A will measure the time it takes for ten pulses. O-B will observe what happens.

H. Rotate and repeat G. Try to keep the amplitude constant between all measurements. Discuss your observations with the group and record data.

- ANALYSIS -

I. How does the displacement forward or backward change with amplitude of a pulse? Make a graph in your notebook of amplitude on the x-axis and displacement on the y-axis. Be sure to show your units.

J. How does the displacement forward or backward change with the frequency of a wave? Make a graph in your notebook of frequency (pulses/second) on the x-axis and displacement on the y-axis.

Lesson 5	Traveling On
Overview Standard(s) & Objectives	**Overview** How are the properties of sound wave (amplitude, frequency, wavelength) related to each other and to the speed of the wave moving through matter? Students continue investigations of the properties of traveling waves using springs. They consolidate their understanding through an analysis of results, development of models and explanations. **Building Toward** **MS-PS4-1, MS-PS4-2** Crosscutting Concept/SEPs • Conduct Investigations • Analyze and Interpret **Where We Are Going** Students will begin to explore what happens when the energy disturbance which makes up a sound wave reaches a boundary. They will be introduced to terminology covered in the standards (absorption, reflection, transmission) and explore the phenomenon of standing waves. Standing waves are a phenomenon that arise at certain frequencies when a reflected wave adds constructively to an incoming wave. In the next lesson, we will use the properties of standing waves to indirectly determine the speed of a wave. In this lesson, students are moving their thinking from the realm of cause and effect to that of systems and systems modeling, introducing a new crosscutting concept and new vocabulary.
Assessment Opportunities	**Investigating/Analyzing:** Students are participating in the investigation and analysis with their partner. Students are reflecting in their notebooks on the Slide 4 Questions. **Modeling:** Students are contributing to their group's Data Analysis and Modeling charts as evidenced by the color of marker they have been given. Students will summarize what they learned during the lesson by making an analogy table in their notebook; this is the assessment for this lesson.
Materials	Per Student: • Science Notebook Per Group (4 Students) : • Task Card 5-1 • Set of Springs, 1 long & 1 short • Meter Tape or Meter Stick • Masking Tape • Timer • Graph Paper (print master) • Task Card 5-2 • Chart Paper & Markers (teacher provided) Per Classroom: • Computer, Projector

	• PowerPoint
Preparation	• If utilizing hand graphing, print enough sheets of graph paper for each group to have two-four sheets. • The room should be set up so that groups of four or five students can work around tables or lab benches that are at least 4 meters long (or on the floor). If using the floor, we suggest finding a non-carpeted area.
Part 1. What is the relationship between amplitude, frequency, wavelength, and the speed of a wave through a medium? Materials: Task Card 5-1, Masking Tape, Meter Stick/Tape, Springs, Timer	
Student Practices	• Planning and carrying out investigations • Analyzing and interpreting data • Making mathematical representations
Instructions	*DRIVING QUESTION: What is the relationship between amplitude, frequency, wavelength, and the speed of a wave through a medium?* 1. If groups did not have time to graph their data from the Lesson 4 investigation, give them the opportunity now. They will be working in the same groups for today's activities. 2. **Slide 1** defines one more term that is used to describe wave properties, **wavelength.** One wavelength is the distance between two compression region or two rarefaction regions in a longitudinal wave. Give students a minute to think about the question under the diagram. Is wavelength correlated with amplitude, frequency or both? Have students consider their earlier investigations as they think about the question and write down some ideas. Have students compare their ideas with a partner, then ask a few pairs to explain their answers and reasoning. 3. Break students into the same groups as in Lesson 4 as much as possible (4 students/group is optimal (and minimum)) and pass out Task Card 5-1. Each group will get two springs (one long and one short), either metal or nylon, to start this activity, along with a timer, masking tape and a meter stick or tape. Halfway through they will switch springs with another group. 4. Once students have collected their data, have them turn the Task Card over and as a team finish the analysis and interpretation of their data (have groups keep their equipment for now). They will be adding the frequency data to a class graph. This can be done on a whiteboard or using Excel, DESMOS or other software. If students have computers, they can add their data to a class spreadsheet using Google Sheets. Make sure that the data for metal springs and nylon springs are kept separate. 5. **Slide 2** defines the speed of a wave in meters / second as frequency (1/sec) x wavelength (meter). Using the class spreadsheet or graph, calculate the speed by multiplying the two quantities. On average, the product should be a constant for each type of spring. 6. Have students brainstorm with their group on how they could directly measure the speed of the spring wave and try it with whichever type of spring they have currently. *We recommend using the long metal spring or a*

	short nylon spring, but students might try both. We recommend timing a pulse wave for a fixed length. 7. Collect the results of the measurement from each group and put on the whiteboard or into the class graph. Did the direct measurement agree with the calculation for the two types of springs? Have students reflect using the questions on **Slide 3.**
Resources and Teaching Strategies	Think-Pair-Share
Part 2. How do the investigations we have done on the properties of waves using springs help us to build a model for the understanding of sound waves moving through air? Materials: Computer, Projector, PowerPoint, Chart Paper, Markers	
Student Practices	• Asking questions
Instructions	*DRIVING QUESTION:* How do the investigations we have done on the properties of waves using springs help us to build a model for the understanding of sound waves moving through air? 1. Students should stay in the same groups. For each group, pass out a Lesson 5-2 Task Card, two sheets of chart paper, and 4-5 markers (each student should have a different color). Each person will write their name at the top of each sheet in their color. Everyone should contribute using their own color and not trade markers. The back of the task card shows how each chart paper should be set up. 2. Once everyone has their chart papers set up, put up an animation of a sound pulse on **Slide 4**; let it run for students to look at while they are completing the tasks. 3. When students have completed their charts, have them put them up on the wall and give the class time to do a 'gallery walk'. Each group should look at the other groups' work together and discuss the following: a. Did another group include something in one or more of their model drawings that your group didn't think of? b. Did all groups see the same kind of correlations in the data? c. Any other differences you notice between what your group thought, and other groups thought. 4. Once the gallery walk is complete students should return to their seats and summarize what they learned by making an analogy table in their notebooks using the template on **Slide 5**, then filling it in. 5. When students are finished, ask them about the analogy they drew between increasing the amplitude in a spring wave and a sound wave. Did everyone think that a bigger amplitude sound wave would be louder or

	have higher volume? If a sound wave acts like the spring did, what is happening to the air molecules for a higher amplitude sound wave? For sound waves, the amplitude of the wave is its loudness. The physical unit of loudness is **decibel**s. The table on **Slide 5** shows the decibel scale for some commonly encountered sounds. The decibel scale can be converted to the pressure (Force/surface area). Typical units are Newtons/meter^2. The conversion is not linear: At 110 decibels, the pressure is 100,000 times more than at 10 decibels.
Teaching Strategies	Think-Pair-Share ATTENTION TO EQUITY: An Equity strategy to ensure all students contribute to the activity.
Science Concepts and Vocabulary	**Wavelength –** The distance between adjacent identical parts of a wave cycle is called the wavelength. For example, the wavelength of a sound wave would be the distance between two compression regions. **Wave Speed** – The wave speed is the speed at which energy is transferred through a medium in a wave. **Decibel** – The amplitude of a sound wave.

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Task Card - Lesson 5-1 Part A. Investigate

DRIVING QUESTION. What is the relationship between amplitude, frequency and wavelength in a wave?

ONE PERSON WILL GENERATE THE WAVES, A SECOND WILL HOLD THE END FIRMLY, WHILE THE OTHERS TAKE AND RECORD DATA. ROTATE ROLES FREQUENTLY.

DECIDE AS A TEAM HOW TO INVESTIGATE EACH QUESTION (DATA TABLE, PROCEDURE, CONTROLS, ETC.). INVESTIGATE WITH BOTH THE SHORT SPRING AND LONG SPRING.

1. Practice making a periodic wave and decide how to determine the wavelength.
2. Does the wavelength change as a function of the amplitude?
3. Does the wavelength change as a function of the frequency?
4. Does the length of the spring matter?
5. Choosing one of the springs, measure the wavelength at three different amplitudes.
6. Choosing one of the springs, measure the wavelength at three different frequencies.

TRADE SPRINGS WITH ANOTHER TEAM SO THAT YOU HAVE THE OTHER MATERIAL (METAL OR NYLON) AND REPEAT THE INVESTIGATIONS.

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Task Card - Lesson 5-1 Investigate

DRIVING QUESTION. What is the relationship between amplitude, frequency and wavelength in a wave?

ONE PERSON WILL GENERATE THE WAVES, A SECOND WILL HOLD THE END FIRMLY, WHILE THE OTHERS TAKE AND RECORD DATA. ROTATE ROLES FREQUENTLY.

DECIDE AS A TEAM HOW TO INVESTIGATE EACH QUESTION (DATA TABLE, PROCEDURE, CONTROLS, ETC.). INVESTIGATE WITH BOTH THE SHORT SPRING AND LONG SPRING.

1. Does the wavelength change as a function of the amplitude of a pulse wave?
2. Does the wavelength change as a function of the amplitude of a periodic wave?
3. Does the length of the spring matter?
4. Choosing one of the springs, measure the wavelength at three different amplitudes.
5. Does the wavelength change as a function of the frequency of a periodic wave?
6. Does the length of the spring matter?
7. Choosing one of the springs, measure the wavelength at three different frequencies.

TRADE SPRINGS WITH ANOTHER TEAM SO THAT YOU HAVE THE OTHER MATERIAL (METAL OR NYLON) AND REPEAT THE INVESTIGATIONS.

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Task Card - Lesson 5-1 Part B. Analyze and Interpret

1. Plot your data for wavelength as a function of amplitude, plotting both sets of data on one plot. Then decide as a team:
    a. Is there a correlation between amplitude and wavelength? If so, is it positive or negative?
    b. How does the material the spring is made of affect the results and conclusions? Give your reasoning.
2. Plot your data for wavelength as a function of frequency, plotting both sets of data on one plot. Then decide as a team:
    a. Is there a correlation between frequency and wavelength? If so, is it positive or negative?
    b. How does the material the spring is made of affect the results and conclusions? Give your reasoning.
3. You will be adding your groups' data to a class graph of frequency versus wavelength. Follow your teachers instructions for adding your data to the other teams.
4. Once the class graph is made, decide as a team whether you want to modify or add to your answers in 2a and 2b.

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Task Card - Lesson 5-1 Part B. Analyze and Interpret

1. Plot your data for wavelength as a function of amplitude, plotting both sets of data on one plot. Then decide as a team:
    a. Is there a correlation between amplitude and wavelength? If so, is it positive or negative?
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    b. How does the material the spring is made of affect the results and conclusions? Give your reasoning.
3. You will be adding your groups' data to a class graph of frequency versus wavelength. Follow your teachers instructions for adding your data to the other teams.
4. Once the class graph is made, decide as a team whether you want to modify or add to your answers in 2a and 2b.

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Task Card - Lesson 5-2
Analyze and Model

DRIVING QUESTION. How does the displacement in a pulse wave or periodic wave correlate with amplitude and frequency?

MATERIALS: *Chart paper, markers*

1. On the first sheet 'Models', work together to draw models in each box of what a periodic wave of sound or in a spring look like. Draw arrows between features that are the same between two models (for example, the movement of the yarn and the displacement of air). Label the regions (compression and rarefaction) and show the wavelength.
2. On the second sheet 'Investigations', the first column is labeled 'Amplitude' and the second column is labeled 'Frequency'. Tape the displacement and wavelength graphs you made in the correct columns. Decide as a group and write below each graph:
   - A. Does this graph represents a positive correlation, a negative correlation or no correlation between amplitude/frequency and displacement?
   - B. Add an analogy table to each column:
     1. In our investigation with a spring, we made larger amplitudes/frequencies by ________ .
     2. In sound, a larger amplitude pulse or wave (or larger frequency wave) would be made by ____________________.

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Task Card - Lesson 5-2
Analyze and Model

DRIVING QUESTION. How does the displacement in a pulse wave or periodic wave correlate with amplitude and frequency?

MATERIALS: Chart paper, markers

1. On the first sheet 'Models', work together to draw models in each box of what a periodic wave of sound or in a spring look like. Draw arrows between features that are the same between two models (for example, the movement of the yarn and the displacement of air). Label the regions (compression and rarefaction) and show the wavelength.
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   - A. Does this graph represents a positive correlation, a negative correlation or no correlation between amplitude/frequency and displacement?
   - B. Add an analogy table to each column:
     1. In our investigation with a spring, we made larger amplitudes/frequencies by ________ .
     2. In sound, a larger amplitude pulse or wave (or larger frequency wave) would be made by ____________________.

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Task Card - Lesson 5-2 Analyze and Model

CHART PAPER 1

MODELS

Names:

Pulse | Wave

Sound

Spring

CHART PAPER 2

INVESTIGATION

Names:

Amplitude | Frequency

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Task Card - Lesson 5-2 Analyze and Model

CHART PAPER 1

MODELS

Names:

Pulse | Wave

Sound

Spring

CHART PAPER 2

INVESTIGATION

Names:

Amplitude | Frequency

<table>
<tr><th>Lesson 6</th><th>Bouncing Back</th></tr>
<tr><td>Overview Standard(s) & Objectives</td><td>Overview
What happens to sound at a boundary?

Students make predictions and learn terminology to describe what will happen when a longitudinal wave (sound, spring) reaches a boundary.

MS-PS4-1, MS-PS4-2

Crosscutting Concept/SEPs
Ask Questions and Develop Models
Conduct Investigations
Where We Are Going
Students will begin to explore what happens when the energy disturbance that makes up a sound wave reaches a boundary. They will be introduced to terminology covered in the standards (absorption, reflection, transmission) and explore the phenomenon of standing waves. Standing waves are a phenomenon that arise at certain frequencies when a reflected wave adds constructively to an incoming wave. In the next lesson, we will use the properties of standing waves to indirectly determine the speed of a wave.

In this lesson, students are moving their thinking from the realm of cause and effect to that of systems and systems modeling, introducing a new crosscutting concept and new vocabulary.</td></tr>
<tr><td>Assessment Opportunities</td><td>Explaining: Check that each student has written down predictions about what happens when an energy pulse is sent down a spring unti it reaches a barrier in several conditions.</td></tr>
<tr><td>Materials</td><td>Per Student:
Science Notebook
Index Card
Straws
Ruler
Scissors (teacher provided)
Per Pair:
Task Card 6-1
One of the following:
Group A: Spring and Strip of Foam
Group R: Spring w/ attached ring, duct tape, ring stand
Group T: Coupled Springs
Per Group (3 students):
Timer (2)
Per Classroom:
Computer, Projector (teacher provided)
PowerPoint
2”x4” Boards (2)</td></tr>
</table>

	• 100’ Measuring Tape

Preparation	• Prepare up to five sets of materials for each expert group (depending on size of class):
	  • Group A: Metal spring and strip of foam; students will run the foam through the spring (see photo A)
	  • Group T: Take a regular length metal spring and a regular length nylon spring (3” diameter each) and use three strips of electrical tape to couple them together (see photo T)
	  • Group R: Put a metal key ring on the end of a metal spring so it can slide over a ring stand; each group gets a strip of duct tape, the spring and a ring stand (see photo R)
	

Part 1. What happens to a sound wave when it reaches a boundary with another material? Materials: Computer, Projector, PowerPoint, Index Card, Task Card 6-1, Talking Sticks	
Student Practices	• Asking questions
Instructions	*DRIVING QUESTIONS: What happens to a sound wave when it reaches a boundary with another material?* 1. So far, we have figured out some information about the sound of thunder. We know it can be produced when the energy transferred from a bolt of lightning causes a wave of pressure in the air, and we have determined

some of the properties of the sound wave as it moves through the air. What happens to it next? Hand out an index card to each student, and then put up **Slide 1** with Question 1**.** Ask the students to think about the question and guess an answer based on what they have learned about sound waves so far. On one side of the card, they should write the question number and the letter of the answer they think is closest to correct, large enough for the teacher to see from the front of the room. They should explain their reasoning under their answer.

> QUESTION 1: A flash of lightning strikes on a flat, open prairie and produces a loud clap of thunder. What is the furthest it might be heard? Explain your reasoning.

2. Click again to reveal Question 2, and ask students to turn their card over and do the same thing for this question.

> QUESTION 2: A flash of lightning strikes in the Black Hills and produces a loud clap of thunder. What will happen to the sound of the thunder when it reaches a hill? Explain your reasoning.

3. When everyone has had time to make their predictions, ask them to hold up their answer to Question 1 so that you can see it. Randomly pick a couple of students to explain their thinking as to why they guessed what they did. Don't tell students the correct answer (B); when they ask, tell them it will be revealed by the end of the lesson.

4. Ask them to turn the card over and reveal their answer for Question 2. Again, pick random students to explain what answer(s) they thought would be most likely. Put up **Slide 2,** which repeats Question 2, but defines some science terminology - **absorption, transmission,** and **reflection.** These terms describe the three major things that can happen to a wave at a boundary, including sound waves such as thunder and light waves such as lightning. Students may be familiar with some of them. Give students a few minutes to write down the definition of these terms in their own words in the glossary of their notebook, and to use the science terminology to rewrite their prediction and explanation for it into their notebooks.

5. (**Slide 3)** Ask students to think about and write down some examples they might think of from everyday life of sound absorbing (A), transmitting (T), or reflecting (R) when it reaches a barrier. While they are thinking, make three columns on the white board or chart paper and label the three actions. Give students time to discuss their examples with a partner and then have groups share out while you list the examples in the table. Then randomly assign each pair one of the columns. Have them think about Questions 3a and 3b on the slide, then brainstorm with their partner**.**

6. Pass out Task Card 6-1 (the correct one for each group) and give students a chance to read the front and ask clarifying questions. *NOTE: If students have not used Talking Sticks before, explain that they will only be able to talk when their pair has the talking stick and everyone else needs to listen intently.* Assign one area of the room to each wave boundary action (A, T, and

	R) and have students take their notebooks and task cards and convene an expert group with the other pairs who considered the same boundary action. Give each group a talking stick and have them pass it around so that each pair has a chance to speak to each question (this time the other member of the pair will speak). 7. Once the talking stick has gone around the circle twice, everyone can turn the Task Card over and look at the hints for how the process could be modeled with a spring. Students should talk it over the suggestions as a large group, then break back into their pairs and try the ideas. Your teacher will have the materials ready for you. 8. After making the suggested observations, have students return to their expert group and discuss what they noticed. How does it relate to sound waves at a boundary? Then decide as a group three things that the rest of the class should know about how the material at the boundary affects what happens to the wave and the energy it carries. Everyone writes them down. 9. Have students return to their seats and rearrange them into groups of 3-4. There should be at least one student from each expert group in the new group. a. Starting with absorption, Expert(s) A will explain to the rest of the group how they modeled absorption with a spring and foam and the three things they should know about how and why a boundary material might absorb the energy of a sound wave. Everyone should take notes in their notebooks when other experts are talking as they will need the information later. b. Repeat the same thing for transmission. Now Expert T is in charge and will explain how they modeled transmission with coupled springs, and the three things the group decided was important for everyone to know. c. Repeat the same thing for reflection. Now Expert R is in charge and will explain how they modeled transmission with how a spring was fixed to a ring stand, and the three things the group decided was important for everyone to know.
Teaching Strategies	TAKING THE PULSE OF THE CLASS: This is another technique that can be used to test prior knowledge at the beginning of a new topic or lesson; later, it can also be used as a quick formative assessment to check whether students are ready to move on to the next bit of figuring out. Think-Pair-Share This learning strategy is called a jigsaw. Each student (or pair in this case) will become an expert in one aspect of a topic and bring that expertise to their fellow students.

Part 2. How can reflected waves help us measure the speed of sound? Materials: Task Card 3 (Part A), Talking Stick, Computer, Projector, PowerPoint	
Instructions	*DRIVING QUESTION. How can we use reflected waves to directly measure the speed of sound?* 1. Staying in the same groups of 3-4 students, put up **Slide 4** and have each group discuss the questions on the slide? Then discuss as a whole class? Do students think that it would be possible to measure the speed of sound reflecting (echoing) from a building? Why might using reflection be an advantage? Ask students to think back to their measurement of the speed of sound in a spring and write an analogy in their notebooks between the two situations. Did they use reflection as a tool when they did that investigation? How could it be an advantage? *TEACHER TIP: If time permits and most groups did not consider using the reflected wave in their speed of sound measurement in a spring in Lesson 5, they could try it quickly.* *TEACHER TIP: If the weather or time precludes going outside to try this experiment as a class, there is data in the video linked later that can be used to calculate the speed of sound.* **2.** Choose one group of 3 to be in charge of measuring the distance and give them the 100-ft rule (2 students will handle the rule and one will record the distance data). In the other groups, two students will be timing the sound and one person will record the time data. **3.** Head outside to an open area across from a flat wall of the school or other nearby building. While the distance group is measuring the distance to the building, have the remainder of the students practice measuring the time between the initial clap of the two boards and echo. They will find it difficult because the time will be very short. **4.** One way to reduce timing errors in this method is to clap the boards together in time to the echoes. This means that the time between each clap is the journey time for the sound. Students can then measure the time for 11 claps, which is the time for 10 journeys by the sound. This time can then be used to calculate an average time for the sound to travel to the wall and back. **5.** After each group has collected six data points (three by each method), while everyone else remains very quiet, assign a few pairs to use their phones to record video of the experiment done using both methods. This video can be slowed down by a known amount to get a more accurate measurement of the time difference. **6.** Everyone returns to the classroom. Have the recorder for the distance group write the distance to the wall on the whiteboard. Then have each group calculate the speed of sound from their average time data using both methods, writing their groups results for each method in a table on the whiteboard. (Remind them to convert the distance from feet to meters, and that the total distance is double the measurement.) Then calculate a class average. This

	average will be compared with the result found by other classes, and with the indirect method they will use in Lesson 7. *Don't tell the students yet, but the speed of sound in air is approximately 334 meters/s (will vary with temperature and pressure).*
Science Concepts and Vocabulary	**Absorption (v. absorb) –** Absorption, in wave motion, is the transfer of energy into the surround medium. Eventually, the wave will run out of energy. Another word for absorption in this context is attenuation. **Transmission (v. transmit) –** When a wave arrives at a boundary between two materials, part or all the wave energy can be transmitted to the new medium. The type of wave, its properties, and the difference between the two media will determine what happens to most of the wave energy. **Reflection (v. reflect) -** When a wave arrives at a boundary between two materials, part or all the wave energy can be reflected into the original material and travel the other direction. The type of wave, its properties, and the difference between the two media will determine what happens to most of the wave energy. **Echolocation –** process for locating objects by sound waves.

Lesson 7	Or Just Standing Still?
Overview Standard(s) & Objectives	**Overview** How can we measure the speed of sound in air? We explore the interference that happens when an energy pulse reflects back and collides with another energy pulse, and how at certain frequencies, a phenomenon called standing waves occurs. We will see how the properties of standing waves in tubes can be used to measure the speed of sound in air indirectly in a tabletop experiment. **MS-PS4-1, MS-PS4-2** Crosscutting Concept/SEPs • Conduct Investigations • Analyze Mathematical Equations

<table>
<tr><td></td><td>Where We Are NOT going
In future lessons we will get to the idea that because the object making the sound initially deforms in the direction the force is traveling, the particles of the medium get compressed and then expand, bumping into their neighbors, and thus the resulting compressions and decompressions result in a sound wave. Without noting the deformation beyond the original starting position, it’s difficult to explain why the particles of air or other media are affected by an object vibrating. This deepening definition of vibration also sets up an understanding that will be developed in grades 9-12 regarding the intermolecular forces that are at play.

Although this intermolecular understanding is beyond this grade band, one can see the learning progression of the definition of vibration. In high school physics classes and beyond, this mechanism will also help account for normal forces on objects at rest on the ground.</td></tr>
<tr><td>Materials</td><td>Per Student:
Science Notebook
Per Pair:
Task Card 7-1
Scoth tape
Scissors
Ruler
Straws
Per Group (4 students):
Task Card 7-2
Spring
1” outer tube w/ stopper – filled with water to mark
½” diameter inner tube
Meter tape
Two tuning forks
thumper
Per Classroom:
Computer, Projector (teacher provided)
PowerPoint
Vaseline</td></tr>
<tr><td>Preparation</td><td>Prepare outer tubes for each group for Part 3 – use petroleum jelly on a rubber stopper and push firmly into the bottom of a 1” tubing to prevent leaking. Check that the seal is watertight. Then clamp the tube to a ring stand and set on a lab bench or table with two tuning forks and a thumper. (One of the tuning forks should have a frequency > 320 Hz).</td></tr>
<tr><td colspan="2">Part 1. What are standing waves, how are they formed, and what are their properties?
Materials: Task Card 3A, Talking Stick, PowerPoint</td></tr>
<tr><td>Instructions</td><td>DRIVING QUESTION. What are standing waves, how are they formed and what are their properties?</td></tr>
</table>

	1. **(Slide 1)** Start the class by having students watch the video linked from Slide 1. The performance in the video uses several phenomena related to sound and light. Have students follow the guidance on the slide while they watch the video and compare notes with a partner. 2. After students have had a chance to think about how they can explain one of the phenomena about sound in the video, have them jot down some notes. Then poll the class using **Slide 2**. Have students keep their fingers up while you pick two random students for each choice to call on later. Make a table of the three phenomena on the Whiteboard or chart paper. For each one, ask one student to explain how sound waves might cause the phenomenon. Then ask the second student to add to that explanation or make an alternate explanation. 3. Discuss as a class. Is it possible to explain all of these phenomena using the properties of sound waves that have been discussed so far: the properties (frequency, wavelength and amplitude), how they transfer energy, and how they interact with boundaries (absorption, transmission, reflection)? Students should conclude that there is more happening than can be explained with what we learned so far. 4. Tell students you found another interesting video of compression waves reflecting from a boundary. Ask students to make a t-chart in their notebook to record what they notice and wonder as they watch Video #17 (linked from **Slide 3).** Have students compare their notices and wonders with the same partner. The video will pause at a couple of points with some questions for the students. Does the video change their thinking about what happens to a spring in any of the scenarios? Give them a chance to make changes to their predictions. 5. In the video, what defined a **standing wave?** A **node**? An **antinode**? Use **Slide 4** to relate the nodes and antinodes of a standing wave to the displacement and pressure of the air in a sound wave. 6. Have students return to the sound phenomenon they tried to explain from the first video. Does an understanding that reflected waves can make a standing wave at certain frequencies make it easier to explain that phenomenon, or not. Have them write a reflection and draw a model in their notebook. While they are doing this play the video again on loop in case, they want to study it again with their new knowledge. 7. (OPTIONAL) Students can make their own Chladni plate following the instructions in the optional extension section. Experiment with the Chladni plate using different frequencies of tuning forks and draw the patterns.
Resources and Strategies	Don't ask for volunteers. Pick a student at random and then the second one also at random.
Part 2. What are the properties of standing waves using a spring and sound in a tube (closed or open)? Materials: Computer, Projector, Task Card 7-1, Long Spring, Timer, Masking Tape, Meter Tape, Marker	

Instructions

DRIVING QUESTIONS: How does the speed a longitudinal wave transfers energy through a spring vary with amplitude, frequency, and the properties of a spring?

1. Break the class into groups (4 optimal) and pass out Task Card 7-1. Turning the Task Card to Part A, each group will practice making a longitudinal standing wave in a spring as was done in the video. Groups will have their choice metal or nylon, short or long spring, but they can only 'check out' one spring at a time. Once they find a configuration that is a standing wave, find the nodes and antinodes using a scrap of paper as was done in the video and mark them with masking tape on the floor or table. Find the frequency and wavelength. Make a table in student notebooks with all the data. Then repeat for a second frequency.

2. When students are done with Part A, they can turn the Task Card over and do Part B individually. Once they have made a set of pan pipes, try blowing across the top of each straw to make a sound. Try it with.

3. For each student, pass out 2-3 straws and an instruction sheet for today's homework assignment to make a set of pan pipes (could be done in class). Students will need their pan pipes in Lesson 5. Put up **Slide** 1, and let students know that today we are going to measure the Standing Wave Data.

Standing Wave Data

Type of Spring	Trial/Group#	Frequency (*f*) *(1/s)*	Wavelength(λ) (m)	f* λ (m/s)

4. Groups will collect the data for Part A and average three trials to get the speed of a compression pulse for their spring. Then they will transfer the standing wave data they took in Lesson 4 (either Station 5 or 6 depending on which type of spring they have today). They will calculate the product of frequency x wavelength (f* λ) in units of meters/second (m/s).

5. As groups are transferring their data and calculations to the class graphs ask the rest of the class to think about their data and the collective class data. Does the standing wave f* λ data give the same result as a direct measure of the speed of a pulse for a particular type of spring? How is this possible? *HINT: Think about the conditions for getting a standing wave.* Put up **Slide 3** and give

<table>
<tr><td></td><td>students a couple of minutes to answer the reflection questions. Then have them discuss them with a partner and ask each pair to share out one thought, idea or wonderment.</td></tr>
<tr><td>Resources and Teaching Strategies</td><td>Teach-Pair-Share</td></tr>
<tr><td colspan="2">Part 2. How can we measure the speed of sound in air indirectly using standing waves?
Materials: Speed of Sound Apparatus, Tuning Forks, Thumper, Meter Tape</td></tr>
<tr><td>Instructions</td><td>DRIVING QUESTION. How can we measure the speed of sound in air indirectly using standing waves?

1. Ask students to go back to Lesson 4 data sheets and look at Station #5 or #6 standing wave data again. They should use it to answer the reflection questions on Slide 4:

a. How many nodes and antinodes were found in one wavelength?

b. Draw a picture of the standing wave in the spring and mark the compression and rarefication regions and the nodes and antinodes.

c. At a node, the displacement of a coil of the spring was (write down all that apply)?

Large and forward Zero Large and backward

d. At a node, the coils of the spring were (write down all that apply)?

Compressed together At equilibrium Stretched apart

e. At an antinode, the displacement of a coil of the spring was (write down all that apply)?

Large and forward Zero Large and backward

f. At an antinode, the coils of the spring were (write down all that apply)?

Compressed together At equilibrium Stretched apart

2. Put up Slide 5 with an animation of a standing longitudinal wave. Give students a few minutes to talk with a partner. Does this animation fit their answers to the questions? What is happening to the displacement of air particles at a node? Antinode? Give students a chance to write down any changes they want to make to their reflections after watching the animation.

3. Have students get out the set of pan pipes they made as homework and put-up Slide 6. When a standing wave is confined to a pipe, things are more complex. Each length of pipe will have natural frequencies and resonances that are set up by standing waves. The natural frequencies have harmonics. A longitudinal standing wave in an open tube has maximum displacement antinodes at each end. This leads to the harmonics shown on the</td></tr>
</table>

slide. When one end is closed, then the standing wave has a node at that end. Have students try blowing across their straws with and without their finger over the bottom and listen to how the natural frequency changes. These harmonics are also shown on the slide.

4. This property of how a standing wave behaves in a closed tube will be used to measure the speed of sound in air. Have students work in the same groups as they did for Part 1 and turn their task card over for their instructions. The outer tube should be set up in advance on the ring stands and tested to make sure they are watertight. Two groups can use each ring stand if the classroom does not have some (four are provided in kit).

5. Once students have collected data (they should have found the first resonance (L1) for both tuning forks and maybe the second resonance (L3) as well (the second resonance will not be reached for the lowest frequency tuning forks with this apparatus). Have them average their values and make a table in their notebooks using the template shown on **Slide 7.** *An Excel file with theoretical values for each tuning fork is on the Flash drive.*

6. The same groups should work together to calculate the wavelength (λ) of the standing wave and from that the speed of sound, $f*\lambda$. Students should remember that L1 = $\frac{1}{4}*\lambda$ and that L3 = $\frac{3}{4}*\lambda$. Students can calculate the speed from L1 directly or from the difference L3 – L1. The latter is more accurate as there is a correction factor right at the end of the tube which is eliminated when the difference is taken. How does the speed of sound in air measured this way compare with the direct measurement made in Part 2? Have students reflect in their notebooks about which method they think is more accurate.

7. Put up **Slide** 8, which gives the scientifically accepted value for the speed of sound in air (343 m/s). Then ask students to turn back to their analyzed data from Lesson 5 and individually answer the following questions in their notebooks (listed on slide).

a. If the speed of sound given on the slide is correct, then our group got the most accurate results when we __________________ .

b. In the indirect measurement of the speed of sound (Part 3), what are some reasons we may have gotten a different answer?

c. In the indirect measurement, why could it matter whether we calculated the speed from the 1st harmonic or from the difference of the 3rd and 1st harmonics?

d. (If the class did Part 2) In the direct measurement of the speed of sound (Part 2), what are some reasons we might have gotten a different answer?

8. Can we explain the Flash-to-Bang method for finding the distance to a thunderstorm (1 mile for every 5 seconds) using the accepted speed of sound. Have students use the conversion factor given on **Slide 8** to

	convert 343 m/s to miles/second. If sound travels that many miles in a second, how many miles does it travel in 5 seconds?
Science Concepts and Vocabulary	**Acoustics-** the science concerned with the production, control, transmission, reception, and effects of sound. **Cymatics-** the study of visible sound vibration and shows the transformational nature of sound and matter. **Chladni plate -** consists of a flat sheet of metal, usually circular or square, mounted on a central stalk to a sturdy base. When the plate is oscillating in a particular mode of vibration, the nodes and antinodes that are set up form complex but symmetrical patterns over its surface. The positions of these nodes and antinodes can be seen by sprinkling sand upon the plates; the sand will vibrate away from the antinodes and gather at the nodes. **Standing Wave –** A standing wave is a particular vibration of a system in which some points of the wave are stationary (zero displacement) and other points are vibrating wildly (maximum displacement). **Node –** A node is a point on a standing wave with zero displacement. **Antinode –** An antinode is a point on a standing wave with maximum displacement. **Natural Frequency -** The frequency or frequencies at which an object tends to vibrate with when hit, struck, plucked, strummed or somehow disturbed is known as the natural frequency of the object. **Resonance –** Resonance happens if an incoming wave is close to the natural frequency of an object; the object will start vibrating with large amplitudes. **Harmonic –** A harmonic of a wave is a wave whose frequency is an integer multiple of the frequency of the first wave.

<table>
<tr><th>Lesson 8</th><th>Matter Matters</th></tr>
<tr><td>Overview Standard(s) & Objectives</td><td>Overview
What variables affect the speed at which a wave travels through a medium?

Students will examine the variables that affect the speed of a longitudinal wave as it travels through a medium. They will discover that in gases, the weight of the particles matter. Then they will examine the speed of a wave in liquids and solids.

MS-PS4-1, MS-PS4-2
Crosscutting Concept/SEPs
Analyze and Interpret Data
Expanding Models/Concepts
Where We Are Going
This lesson is tricky as students transition from modeling sound waves in air only to considering the effects of the medium, first for other gases (showing a negative correlation between density and speed), then for liquids and solids (showing the opposite correlation). This will cause many if not all students to make the wrong prediction in Part 2 of the lesson, but that is fine. Research shows that if students get it wrong first, they are more likely to remember the content later.

The reason students will predict wrong is that in liquids and solids, there is a much stronger effect on the speed of a wave that density. This is due to the strong attractive bonds between the particles that is what makes a solid. It also makes energy transfer happen much easier.

Where We Are NOT going
Even though we have to introduce bonds between atoms and molecules in this lesson in order to explain the phenomenon, we will not be addressing what causes those bonds and why some are stronger than others.</td></tr>
<tr><td>Materials</td><td>Per Student:
Science Notebook
Per Group (3 students):
Bag of mini dominoes
Masking Tape
Timers (2)</td></tr>
</table>

	• Meter Tapes (2) Per Classroom: • Computer, Projector (teacher provided) • PowerPoint • Ping-pong ball • Golf Ball • Metal Slinky • Plastic Slinky
Preparation	Groups will need a stable table or area of the floor with about two meters of space to set up their dominoes. The floor will probably work best because of the likelihood of knocking against a table and toppling the dominoes early. We suggest taping off a space for each group with room for students to circulate between taped areas, but not stepping into anyone's section. (Students will get frustrated if they must start over too many times.)
Assessment Opportunities	**Analyzing & Interpreting:** Check that each student has reviewed their notebook, written down four sentence frame questions, and updated their model. Check that each student has written down notices and wonders about the data graph and participated in the Think-Pair-Share discussion. **Modeling:** Observe that each student has written a description of the ball and spring model and its analogy with a sound wave. **Modeling:** The formative assessment for this lesson is the student answers to the questions on Slide 9.
Part 1. What is the speed of a pulse traveling down a spring? Materials: Computer, projector, PowerPoint, Task Card 5-1, Long Spring, Timer, Masking Tape	
Student Practices	• Developing and refining models • Analyze and interpret data • Use mathematical representations
Instructions	*DRIVING QUESTIONS: Is the speed of sound always 343 m/s? Why or why not?* 1. Do sound waves move through empty space? (**Slide 1)** Give students a minute to think about it and write down their ideas. Talk it over with a partner. Then ask them to vote (fist or five). Tell the students that – while you can't transport them to space to do the experiment – you can bring empty space to them. Take the craft stick and hang the bell on the end using the attached paperclip. Carry it around the classroom shaking it so everyone can hear it. Then stick the craft stick to the inside of the bottle lid with the sticky tack and close it up. Carry it around again shaking it gently. *Students should still hear the bell.* Next take the top off, put two lit matches into the bottle, and put the lid on again. *The matches will use up the oxygen in the bottle, lowering the air pressure. This time when you shake it, students will hear nothing, or it will be much reduced in volume.* 2. In their notebooks, have students find the Initial Model Diagram they did in Lesson 1. They will be updating their model for sound so have them review their earlier thinking for how sound moves between a source and detector. Then they should 'touch every page' of their science notebooks from then to now, reminding themselves what they investigated and figured out

about how sound moves through air. Once finished, write down four statements using sentence frames (**I noticed/I learned/ I wonder/ I think**). Remind students that they don't have to use every sentence frame; they can repeat which ones they would like. Based on all they have figured out since Day 1; students should draw an updated model of the 'Sound In Between' portion of their overall model (on the current page of their notebook).

3. Put up **Slide 2** with the question of the day: Is the speed of sound always 343 m/sec? Based on their updated models, have students think about it for a minute or two, then do a class poll on the count of 3: Fist is No, 5-fingers is Yes. Randomly call on a few yays and a few nays to give their reasoning.

4. We can use our equation $v = f*\lambda$ to measure the speed of sound in another gas and see if it's the same as in air. Play Video #11 (linked from **Slide 3**), which shows another way to look at standing waves, with something called a Ruben's Flame tube. In this case, the pressure wave generated by a speaker attached to a device called a **signal generator** is moving through propane, a flammable gas. Play the video through until he reaches a frequency of 440 Hz. The 100 cm scale is marked at that point. Ask for a student volunteer to come up and use a ruler to measure the wavelength and the scale on a screen, and as a class calculate the ratio to get the true wavelength of the tube. (Have students who are watching suggest where the wavelength should be measured. Remember that the full wavelength goes through a node in the middle.) λ/100 cm = measured distance between nodes/measured scale. If time permits, try one or two other frequencies (the video goes up to >1300 Hz. *Sample calculations (for the author's monitor) are given in the Answer Key folder on the flash drive.*

5. The class will find that the speed of sound in propane is less than that in air at room temperature (*the actual value is 258 meters/second).* **Slide 4** gives a table of common gases, classified about whether they are lighter than air, 'neutral density' (about the same as air), or heavier than air. Propane is listed in the third column (heavier than air). Could this be why the speed of sound in propane is lower than in air? Using their model of how sound moves through matter, students should individually reflect on whether or not the weight of the molecules would change the speed of sound, then make a claim in their notebooks, that the weight of the matter the wave is passing through does / does not matter. They should give some reasons for their claim based on their model of a sound wave.

6. Have students share their claims and reasoning with a partner then ask for groups to share out. Did students land on both sides of the issue? Ask them to think about with their partner what new experiment could give evidence to confirm which claim was correct? *They might suggest testing a gas that is lighter than air, or that they test two gases with the same weight, etc.*

7. Let students know that we don't have the time or equipment to test more gases, but that the data is available. Then show the graph on **Slide 5.** Give

	students a couple of minutes to write down some notices and wonders about the graph, then discuss it as a class. Some features to point out: a. The y-axis on the graph is a logarithmic scale. This is a technique used to better represent data whenever there is a wide range of values, making it hard to put on one graph. b. The speed of sound goes down with the weight of the gas (a negative correlation). c. The speed of sound goes up with the temperature of the gas (a positive correlation) but this is a much smaller effect. Do these features give evidence to support the claim and reasoning students made earlier? Give them an opportunity to add to (or change) the argument they made earlier based on the evidence. 8. Point out the helium data on the graph, then ask students if they have ever seen the trick where someone inhales helium gas and then speaks with a high, squeaky voice? Is this a phenomenon that can be explained by the high speed of sound in helium? Show Video #12 (linked from **Slide 6)** for a demonstration and explanation.
Resources and Teaching Strategies	Think-Pair-Share
Part 2. How does a sound wave move through liquids and solids? Materials: Computer, Projector, metal spring, plastic spring	
Instructions	*DRIVING QUESTION: How does a sound wave move through liquids and solids?* 1. Let students know that based on their models for sound moving through molecules, we will make another prediction (put up **Slide 7).** Have them think about the question on the slide and write down their prediction and reasoning. Then poll the class: a. First, hold up 1, 2, or 3 fingers (ice, liquid, steam) indicating which form of water they predict will show the fastest speed of sound. b. Then, do the same thing for the next fastest. c. Then, the slowest. Look around the room and pick a few students who have different answers to give their reasoning. 2. Remind students that in Part 1, we learned that sound moves fastest through lighter gases and slowest through heavy gases. Call randomly on a student to explain that phenomenon using energy transfer. Keep moving around the room until someone comes up with the explanation that it's easier to transfer energy to a lighter object. *If students aren't getting to that explanation, hold up a ping-pong ball and a golf ball and ask them why we didn't use the golf ball when we explored tuning forks in Lesson 2.* Next pose the question, do they think it is easier for energy to transfer in a solid,

	liquid or gas? Give students a minute to add to (or change) their reasoning for their prediction with an explanation that incorporates energy transfer. *3.* Put up **Slide 8**, which shows a standard depiction of states of matter from a student text book, and below it, a model that scientists commonly use to depict waves moving through matter, called the **ball and spring model**. Pull the demonstration set of tennis balls and springs out. Can these help us explain the speed sound moves through various forms of matter? If the ball in the model represent the molecules the wave is moving through, what could the springs in between the balls represent? Have students copy the ball-spring diagram into their notebook and write what they think the analogies are between this model and a sound wave. Then share out with a partner. Call on a few pairs to share. *Students should figure out that the spring represents the attraction between the molecules, which is strongest in a solid and weakest in a gas.* In science, we call the attraction between molecules a **bond.** *4.* Hold up a metal and a plastic spring. Poll the class: Which spring do they think represents a stronger bond? *The metal spring is 'stiffer' and thus should represent a stronger bond.* Next ask students to go back in their notebooks to their Lesson 4 investigation and find their results for Part 4 (comparison of the wavelength and frequency for a metal spring and a plastic spring). Does this data support the idea that a wave will move faster through a metal spring because it is stiffer and transfers energy easier? Have students think about it, share with a partner, then have groups report their ideas.
Part 3. How can we model longitudinal waves in solids, liquids, and gases with dominos? Materials: Dominos, State-of-Matter Card, Meter Tapes (2), Timers (2) Masking Tape	
Instructions	*DRIVING QUESTION. How can we model longitudinal waves in solids, liquids, and gases with dominos?* 1. Can a row of dominos represent the energy transferred by a longitudinal wave? Break students into groups of 3 for this activity and pass out Task Card 6. Each group will first make an analogy table between a row of dominos and a pressure wave moving through a gas. While they are doing that, circulate and give each group a bag of mini-dominos and have them draw a state-of-matter card. The card will tell them the spacing for their set up (o.5 cm (solid, strong bond), 1 cm (liquid, medium bond) or 1.5 cm (gas, weak bond)). 2. Once everyone is done, give them a few minutes to quietly circle around to look at other groups' set ups. Then everyone will write a prediction in their notebook. Which rows will topple fastest? Which slowest? Why? *3.* Each group will topple their row of dominos, with two people in the group timing how long it takes, and one person adding the energy to start the wave. Have each group write their average time (if both timers get an accurate reading) in a table on the board. Use a chart paper to make a class bar graph with the spacing on the x-axis and the time on the y-axis. Video

	#13 (linked from **Slide 9)** shows a direct comparison between 3 rows of dominos representing solids, liquids, and gases. *4.* Give each student time to reflect in their notebook using the questions on **Slide 9**. Their notebook entries are the formative assessment for this lesson.
Science Concepts and Vocabulary	**Signal generator –** An signal generator is an electronic device that will generate a sound wave of a given frequency. **Neutral density –** A neutral density gas is one that has the same mass / volume ratio as air. Since the volume of a gas is only dependent on temperature and pressure, the density of a gas can be replaced by its molecular weight. **Ball and Spring Model –** A ball and spring model is a model used by scientists to describe energy transfer when a wave is moving through a medium. The ball represents a particle in the material of the medium and the strength of the spring represents how strong the attraction is between adjacent particles. **Bond –** A bond is an attractive force between two atoms or molecules. A stronger bond will give the material structure, as in solids. Liquids have weaker bonds and gases much weaker.

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Task Card - Lesson 8
Matter Matters

DRIVING QUESTION. How can we model longitudinal waves in solids, liquids and gases with dominos?

MATERIALS: a bag of dominos and a state-of-matter card, meter stick or tape, two timers.

First make an analogy table in your notebook:
- What do the dominos represent?
- What does the space between dominos represent?
- Where will the wave energy come from?

- VERY CAREFULLY, set your dominos up in a straight line along your meter stick or tape, with the spacing given on your state of matter card.
- When finished, circulate around other parts of the classroom and decide as a group, which dominos do you think will finish toppling first?
- Decide on two people to do the timing and one person to add energy to start your row toppling. Be sure everyone knows how to get a starting time.
- Calculate the speed of toppling for your row (total meters / total time).
- If there is still time, repeat your measurement and calculation.

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- Calculate the speed of toppling for your row (total meters / total time).
- If there is still time, repeat your measurement and calculation.

Print Masters

Norms

- Speak with the promise of being heard and listen with the possibility of being changed.
- Stay engaged and responsive - sustained, voluntary, focused attention.
- Expect and accept non-closure.
- Be willing to experience discomfort.
- Everyone here has expertise to offer. Everyone here has something to learn.
- Pay attention to what peers need (speak loudly enough, include everyone, monitor your airtime, encourage others, ask good questions).
- You have the right to ask questions and the duty to assist.

Lesson 1 Data Table

Record your observations:

Storm #	Clues	Prediction Near or Far	My Time	Partner's Time	Average	Rank by time
1						
2						
3						
4						
5						

- Based on your observations, rank the storms in order based on the time between the flash from the lightning, and the clap of thunder you heard.

Lowest ____ Next Lowest ____Next Highest ____ Next Highest____ Highest ____

- Does the sequence match your predictions if we said the lowest time is the closest, and the highest time is the farthest?

Lesson 2 Data Table

Record your observations:

	Tuning Fork 1	Tuning Fork 2	Tuning Fork 3	Tuning Fork 4
Length in cm				
Stamped # & letter				
A. What do you feel (before thumping)?				
B. What do you hear (before thumping)?				
C. What do you feel (after thumping)?				
D. What do you hear (after thumping)?				
E. What do you hear when you rotate it?				
F. What do you hear/feel when you hold the end to the bone behind your ear?				
G. What happens if you hold the tines to the surface of the water?				

- Based on your observations, rank the tuning forks from the one with the lowest pitch to the one with the highest pitch:

Lowest ___________ Next Lowest _________ Next Highest _________ Highest ____________

- What patterns (correlations) do you notice between the pitch of a tuning fork and your other observations or measurements? Find at least two.

Lesson 3 Data Table

PART A. Amplitude Measurement

	Distance Marker Moved			
Amplitude	Trial 1	Trial 2	Trial 3	Average

PART B. Frequency Measurement.

Amplitude used for all frequency measurements: ________________________

	Total Distance Marker Moved			
Frequency	Trial 1	Trial 2	Trial 3	Average

Sound and Light Refurbishment Inventory

Lesson	*Quantity*	*Item*
All	1	Facilitator Binder w/ USB
	1	Shipping Tote
	7	Talking Sticks
	15	Timers
	15	Rulers
	30	Markers
	7 rolls	Masking Tape
	7	Meter Tapes
	7 sets of 4	Tuning Forks
	1 set of 3	Extra Frequency Tuning Forks
	7	Thumper
	7	Metal Slinky
	7	Nylon Slinky
	7	Bar Clamps
Lesson 1	15	Lesson 1 Task Card
Lesson 2	7	Lesson 2 Task Card
	7	Plastic Tub
Lesson 3	7	Lesson 3 Task Card
	7	Ping-Pongs on String
	7	Wooden 2x4” Stick (4”)
	1 roll	Duct Tape
	7	Ring Stand Clamp
	7	Narrow Markers
	30	Marbles
Lesson 4	7	Lesson 4 Task Card
	Many	Yarn
Lesson 5	7	Task Card 5-1
	7	Task Card 5-2
	14	Chart Paper
Lesson 6	4	A, R, or T Task Card
	4	Strip of Foam
	1 roll	Electrical Tape
	4	Key Rings
	2	Wooden 2x4” Stick (12”)
	1	100’ Tape
Lesson 7	7	Task Card 7-1
	7	Task Card 7-2
	7	Solo Cups
	7	12” Balloons
	7	Rubber Bands
	1 Jar	Glitter
	4	Long Metal Slinky
	4	Long Nylon Spring
Lesson 8	7	Task Card 8-1
	7	Task Card 8-2
	42	Straws
	7	Rubber Stoppers

	7	Outer Tube
	7	Inner Tube
	7	Set of 100 Mini Dominos

NOTICE: THE HEADER/FOOTER AND REVISION HISTORY OF THIS ATTACHMENT IS NOT INCLUDED IN THE PRINTED DELIVERABLE.ANY BLANK PAGES ARE LEFT SO INTENTIONALLY. SOME SECTIONS OF THIS GUIDE ARE CURRENTLY UNDERGOING REVISION AND MAY BE INCOMPLETE AT THE TIME OF THE FIRST VERSION.

Revision History

Rev	Date	Section	Paragraph	Summary of Change	Authorized by
01	2/27/2024	NA	NA	Initial Release	CCR 911