Bend 1 of the Storyline Narrative:
How Can We Sense So Many Different Sounds from a Distance?

Overview of Bend One: *In Bend One, students experience and develop a model to explain a perplexing phenomenon: A cone and needle dragged over the surface of a plastic disc seems to create voices and music. Students then share related experiences, develop a driving question board (DQB), and determine ideas for future investigations. Through the course of this first set of investigations, students seek to answer:*

- *Where does sound come from?*
- *How do different objects make sound?*
- *How are different sounds made?*

These questions motivate the arc of the four bends of this storyline. This first page describes the first bend.

What students figure out: *By the end of Bend One, students discover the underlying principles that explain how different sounds are made. These ideas include:*

- *All solid objects can be deformed (up to a point) and will change shape back and forth for a while after being struck or plucked.*
- *Vibrating matter can produce sound.*
- *The volume and pitch of sound that is produced is related to the amplitude and frequency of vibrations of the sound source.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

MS. Waves and Electromagnetic Radiation		
MS-PS4-1	MS-PS4-2	MS-PS4-3

MS. Motion and Stability: Forces and Interactions	MS. Structure, Function, & Information Processing
MS-PS2-3 (partial)	MS-LS1-8 (partial)

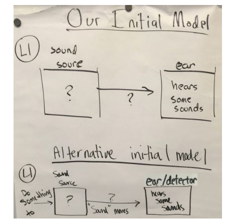
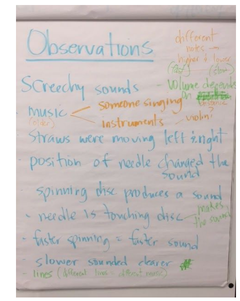
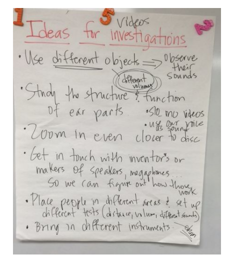
MS. Energy
MS-PS3-5 (partial)

Key to storyline columns:

Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	Phenomena	Lesson Performance Expectation(s):	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
		• **Blue bold font: Science and Engineering Practice** • Regular blue font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena/question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	• Important clues, steps in our thinking, and pieces of the puzzle we uncover • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we have* • **Purple bold font: Our ideas for the next (or future) steps to pursue.**

These materials were developed through with support from the Gordon and Betty Moore Foundation to Northwestern University and support from the NGSX Project at Clark University, Tidemark Institute, and Northwestern University.

This Lesson....What we are doing now: This is the first lesson in the series. Students will observe a perplexing anchoring event: When a sewing needle taped to a cone is dragged over the surface of a plastic disc spun under it, voices and musical notes are heard coming from the cone. You will help students use the observations from this phenomenon to think about other sound-related phenomena, which in turn will lead them to form a broader set of questions about sound to form the Driving Question Board (DQB). Then you will help students brainstorm ways for the class to investigate these questions. These questions and ideas for investigations will motivate and guide the direction of many future lessons throughout the unit.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L1: How can we hear so many different sounds from across the room when we spin the record? <u>3.5 periods</u>: (40 min, 40 min, 40 min, 20 min) *Building toward* ⬇ *<u>NGSS PEs</u>:* *1-PS4-1* *4-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-PS4-3* *MS-LS1-8* *MS-PS3-5*	When a sewing needle taped to a cone is dragged over the surface of a plastic disc spun under it, voices and musical notes are heard coming from the cone.  Other phenomena we recall about sounds we have or haven't heard from a distance.	**Develop an initial model** to describe phenomena and unobservable mechanisms (causes) *that help explain how we can hear so many different voices and sounds (effect) from across the room when we spin the record.* **Ask questions** that arise from careful observation of phenomena and *gaps in our current models to* clarify and seek additional information about patterns in *sound-related phenomena, and* ***ask questions*** *that can be* investigated within the scope of the classroom *to figure out how we can sense so many different sounds from a distance.*	When spinning the record, we noticed that ● we could hear voices, words, and instruments playing songs coming from the cone/record/needle apparatus; ● the closer we were to the record, the louder the sound was; and ● the speed at which we spun the record affected some aspects of the sounds we heard.   We made some initial models. After comparing initial models, we noticed differences in how we presented what was happening at the sound source and in the space between the sound source and our ears. But we also saw common elements such as ● a sound source; ● an ear (or other detector); and ● sound traveling from the sound source to our ears.   We brainstormed some other phenomena we experienced at times when we either could or couldn't hear different sounds coming from various sound sources. These phenomena raised lots of questions. We organized our questions into these categories: ● *Q1: What causes different sounds?* ● *Q2: How do sounds move from a sound source to my ear?* ● *Q3: Why does the same thing sound differently for people in different locations?* **Next steps: After creating a broad set of questions we wanted to answer, we thought of possible ideas for investigations to help us make progress on some of our questions. One idea we had was related to the needle and its interaction with the moving record. We want to see the needle and the record up close where they are touching as sounds are being made.**

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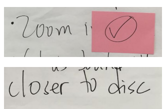
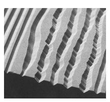
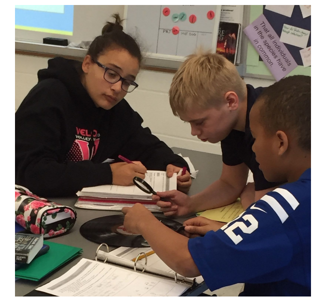
This Lesson….What we are doing now: Because students will have suggested that we need to zoom in and get closer to the needle and the record or need to see it playing again to see what is going on, you will provide them with a series of progressively more detailed inspections of the surface of a record and the needle interacting with it. You help students argue from evidence that the grooves on the record are causing the needle to wobble back and forth in different patterns as it spins.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L2: What does the record look like up close? 1.5 periods: (40 min + 25 min)  *Building toward* *NGSS PEs:* *1-PS4-1* *4-PS4-1* *MS-PS4-3*	A video of a record playing a longer song shows patterns in the motion of the needle across the record surface. A magnifying glass and a piece of a record reveal some patterns in the record structure. Looking at pictures of the record's surface under the microscope reveals patterns in the structures on its surface.  Watching an electron microscope video of a needle on a record player reveals patterns in how the needle moves in relation to the structure of the grooves.	**Analyze and interpret data** *after feeling the surface of the record, looking at it with a magnifying glass, and observing a microscopic view of the record and needle interacting* to provide evidence of (phenomena) *how the structure of the record causes the needle to be pushed to move back and forth in different patterns, and as a result (effect), we hear different sounds being produced.*	 After looking at a piece of the record up close, we noticed some patterns in its structure: ● The record appeared to have lines that form circles around the record. ● When the record plays a song, the needle appears to move from one line to the next. This led us to argue that when the record was spun, these lines (structures) caused the needle to follow them in a spiral around the record, and different lines made different parts of the song (or different songs) play. We brainstormed and generated a new idea: *Maybe there is something different about the structure of lines that would explain why the record sounds different in one groove (or one part of it) as compared to another groove.* This led us to argue that we needed to zoom in closer to look for any visible structural differences in the lines. We noticed some interesting patterns from the electron microscope images: ● The lines on the record are actually grooves with a wavy structure along their edges on some parts of the record's surface. ● The pattern of the wavy structure varies along a groove and between grooves. ● The needle moves back and forth as it moves along the grooves. This led us to propose a structure/function relationship connected to a cause and effect: ● The structure of the grooves causes a push (force) on the needle in different directions as the record spins. ● This generates an effect: The needle is moved back and forth in different patterns. We argued that maybe this moving back and forth in different patterns is what is causing different sounds. **Next steps: We have a new question we want to investigate,** *Do other objects that produce music also move back and forth when they are making sounds?* **To investigate this question further, we want to look at instruments more closely when they are making sounds.**

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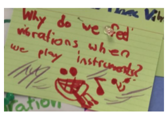
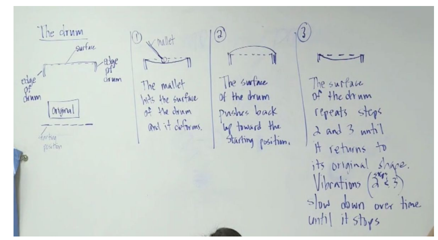
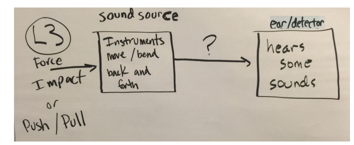
T **This Lesson....What we are doing now:** Students will feel the surface of various instruments after another person strikes or plucks them and connect what they feel to what they observe when they analyze slow-motion videos of those objects. You will co-construct a way to represent the shape changes observed in these objects over time, and students will apply this type of representation to the shape changes they observed in another instrument.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L3: Are other objects that produce music also moving back and forth when they make sounds? **(Includes Embedded Assessment #1)** <u>1.5 periods</u>: (40 min + 20 min) S  *Building toward* ↓ *<u>NGSS PEs</u>:* *1-PS4-1* *4-PS4-1*	Various musical instruments (drums, stringed instruments, and xylophones) that we pluck or strike make a sound, and we can feel a type of motion on them. Slow-motion video of instruments after they are struck reveals patterns in their motion: • Snare Drum • Guitar • Tuning Fork Descriptions of how crickets, grasshoppers, and cicadas make sounds and related slow-motion videos of mosquitoes and bees reveal similar patterns in how they use different body structures to produce sounds.	**Analyze and interpret data** to provide evidence for phenomena *related to the patterns between what we feel on the surface of an instrument after it is struck/plucked and the motion of various musical instruments after they are struck/plucked as seen in a slow-motion video.* **Develop and use a model** to describe (phenomena) *how changes in forces applied to an instrument (being struck or plucked) cause its shape (structure) to change leading it to be repeatedly deformed above and below its initial position (effect) = vibration*; use the model *to argue whether the structure of other solid objects also changes like this (cause) when they produce sounds (effect).*	Since we were wondering whether objects that produce music also move back and forth when they are making sound, we decided to inspect what musical instruments are doing more closely. After touching various instruments that we plucked or struck to make a sound, we noticed a <u>pattern</u>: sound sources felt as if they were moving back and forth slightly when they were making a sound (after striking or plucking them). Also, after watching slow-motion videos of similar objects, we noticed a <u>pattern</u>: we could see the objects (sound sources) changing shape back and forth after being struck or plucked. As a class, we developed an initial explanation as to why the instruments changed shape back and forth after being struck: • When a force is applied to part of an instrument, it <u>causes</u> it to bend/deform and change shape. • When the force is removed, that part of the object springs back and overshoots its original resting position (<u>effect</u>). • Then that part of the object repeatedly bends back and forth for a bit (this is called a vibration) until it stops.  We updated our model to reflect what we discovered. Then, when we started using the model to try to determine how generalizable it was (e.g., when we covered up the word *instruments* on our model), this made us wonder if *our model applies to other things. If instruments move back and forth when they make sounds, do all things move back and forth when they make a sound?*  Some of us thought yes, but others thought no. For the latter, examples of objects like the table or ground were brought up as things that do not vibrate, because they aren't springy like instruments. Not everyone agreed. **Next steps: We want to investigate this new controversy and question in more detail in the next lesson.**

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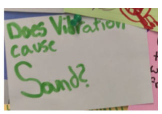
This Lesson....What we are doing now: In the previous lesson, students engaged in a disagreement about whether all objects vibrate when they are making a sound. Now you will introduce how a new type of detector (a laser that shines on a small mirror laid on the surface of another object) works. The students will make predictions about what they would see the detector's laser dot do when a drum and then a table are struck. The results of this test will provide evidence that all objects are elastic (springy) up to a point and that all objects vibrate when they make sound. You will help students apply this new idea back to the needle and record in order to partially answer the question: How does the interaction between the needle and the record produce sounds?

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L4: Do all objects vibrate when they are making sounds? 1 period: (40-45 min) S  *Building toward* *NGSS PEs:* *1-PS4-1* *4-PS4-1*	A mallet striking a drum head with a mirror on it and a laser bouncing off the mirror show a blurred image in the reflected dot for a short duration. A rock dropped on a table with a laser and a mirror provides similar patterns. There are similar patterns in how lasers (and mirrors) are used to measure vibrations of a bell on a big clock (Big Ben) and on the moon.	**Engage in argument with evidence** to support or refute claims *about, "Do all objects* vibrate (cause) back and forth *when they are* making sound (effect)?" *by* providing and receiving critiques about one's explanations and posing and responding to questions that elicit pertinent elaboration and detail *to help determine ways we could gather evidence to answer this question.* **Construct an explanation** based on evidence obtained from previous class investigations and scientific principles to construct an explanation *(as a class) of how the* structure *of the record* causes vibrations *in the needle that lead it to* produce sound (effect) *as the record spins.*	We conducted an investigation with a mirror and laser pointer, table, drum, and rock and noticed a pattern:  • When we struck a drum, the laser beam (dot) bouncing off of a mirror on the drum showed up on the wall or ceiling and moved and shook above and below the point at which it started. • When we dropped a rock onto the table with a laser beam (dot) bouncing off of a mirror on the table, the dot that showed up on the wall or ceiling moved and shook above and below the point at which it started. • The harder we struck either surface, the louder the sound and the more the dot shook back and forth (distance and duration). The results of the experiment provided us evidence to develop some general principles: • All solid objects are elastic (springy) up to a point; they deform when a force is applied to them (we push or pull on them). • Those objects will vibrate back and forth (past their original resting positions) for a bit after the force that originally deformed them is removed. • **Vibrating objects make sound. (1-PS4-1)** We connected these principles to our anchoring phenomena by developing a class-constructed outline for an explanation to answer the question: How does the interaction between the needle and the record produce sounds? We outlined the chain of cause and effect: 1. Because all objects are springy, this means the needle (and/or the record) is springy. 2. As the record spins, wavy grooves in the plastic record move under the needle. 3. The needle is pushed back and forth by the record as the grooves move under it. 4. When the needle is pushed to one side by the grooves in the record, it elastically deforms. 5. When the push is removed, the needle springs back and vibrates. 6. Because all vibrating things make sounds, the needle makes a sound as it vibrates. Developing this explanation led to some new questions: *Was the difference in the pattern in the grooves somehow responsible for all the different sounds we heard? What was different about the vibrations of other objects when they produced different sounds?* **Next steps: We want to study the vibrations from things making different kinds of sounds starting with louder vs. softer sounds (striking instruments harder or softer). We will need a way to detect, look closely, or zoom into the sound source to see how its vibrations compare in these different conditions.**

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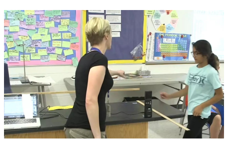
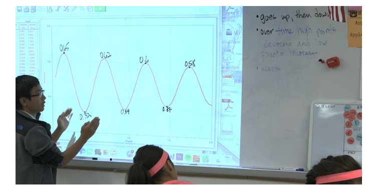
This Lesson....What we are doing now: Students draw on experiences from earlier lessons to argue that hitting, plucking, or striking an object harder causes it to produce a louder sound. They will argue that a wooden stick could be used to simulate the type of shape changes (vibrations) in any sound source. You will demonstrate how a new device (a motion detector) works and students will make predictions about how a graph of distance vs. time for the end of the wooden stick would look for louder vs. softer sounds. The class will collect data from this detector and students will analyze the data, noticing patterns in the graphs that start to introduce some important wave-like characteristics in the motion of the vibrating matter.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L5: How do the vibrations of the sound source compare for louder vs. softer sounds? 1 period: (40 min) S *Building toward* ⬇ *NGSS PEs*: *1-PS4-1* *4-PS4-1* *MS-PS4-1*	Previous phenomena related to the deformation and vibration of the table, guitar string, drum face, and tuning fork when struck. A wooden stick that we clamp down and strike reveals patterns in the position of the end of the stick as measured by a motion detector. 	**Use mathematical and computational thinking** using digital tools to analyze patterns and trends in the graphs *of position vs. time data for large* vibrating *objects to provide evidence of how the y-values (e.g., distance between a peak and a valley) and x-values (e.g., time between a peak and a valley) on the graph compare for deforming it different amounts (simulating what happens when creating* loud vs. soft sounds [amplitude differences]*).*	We thought we could use a long wooden stick to see how the vibrations of the sound source change when it is struck or plucked to make a louder vs. softer sound, because its vibrations could be easier to observe (they are slower), and every object vibrates by changing shape back and forth.  We noticed patterns in the graphs of distance vs. time for the end of the vibrating wooden stick. Some of those patterns changed, while others remained stable. ● The distance from the end of the stick to the detector over time went up and down and changed in a repeating pattern (S-shape turned sideways). ● We decided to refer to each repetition in the pattern as a single wave. ● The high points (peaks) became less high and the low points (valleys) became higher (not as low) as time increased. ● The harder-struck trial resulted in the peaks getting higher and the valleys getting lower on the wave. This corresponded to the stick moving back and forth a smaller and smaller distance (we decided to refer to that distance as amplitude). ● Changing how hard we struck the stick or length of time we measured the vibrations, didn't affect the number of waves that repeated in a certain amount of time (or the time from a peak to a valley). The frequency of the waves was stable (constant). We updated our model to represent what we figured out now that we know a loud sound makes a wave of greater amplitude on our graph and a soft sound makes a wave of smaller amplitude on our graph, but the frequency of the vibrations doesn't change. We started wondering and predicting what the shape of the graph would look like if we make a sound with a different pitch. **Next steps: We start brainstorming how we might investigate our new question and make predictions of what those vibrations might look like. We also want to collect more data on the vibrations from sound sources creating notes with different pitches next time.**

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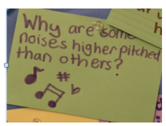
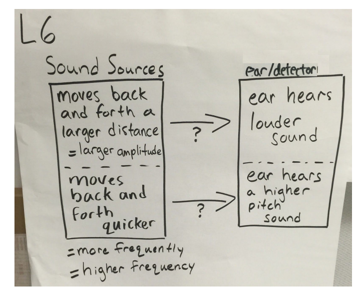
This Lesson...What we are doing now: Students will draw on experiences with instruments and connect those to what they notice in a song playing from small music boxes. This will suggest changing the length of the wooden stick from the last investigation in order to collect useful data on how vibrations at the sound source change due to differences in pitch. You will collect data with the motion sensor to produce graphs that help students notice new patterns of change related to the amount of time a vibration takes (its frequency) for sound sources that produce different pitch sounds (different notes).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L6: How do the vibrations from different sound sources compare for higher vs. lower pitch notes? 1.5 periods: (40-45 min)  *Building toward* *NGSS PEs:* *1-PS4-1* *4-PS4-1* *MS-PS4-1*	A guitar string plucked with a finger pressing on the string at different locations, xylophone bars of different lengths hit with a mallet, and music boxes that we wind and play in our hands show patterns in the pitch of the note and the length of the object that is struck or plucked. We see patterns in the effects on a long, thin wooden stick that we clamp down and strike. Then, using a motion detector, we measure the position of the end of the stick.	**Analyze and interpret data** to determine a causal relationship between the *length of a tine/bar and the pitch of the note produced (effect) by a music box or xylophone.* **Use mathematical and computational thinking** using digital tools to analyze patterns and trends in the graphs *of position vs. time data for vibrating objects of different lengths to provide evidence of how the y-values (e.g., distance between a peak and valley) and x-values (e.g., time between a peak and a valley) on a graph compare for* different pitch sounds. **Develop a Model:** Modify our consensus model—based on evidence—to match what happens if a variable or component of a system is changed, showing *how*	Last time we were wondering: *What would the shape of the graph look like if we make a sound with a different pitch?*  We investigated various musical instruments and noticed patterns in the notes produced by structures in these various instruments (a guitar, a xylophone, and a music box): ● Shorter tines, strings, and bars created higher notes when struck or plucked. ● Something looked different with how the tines were vibrating. This led us to come up with an idea of how we could reuse the wooden stick device and the motion detector to investigate what was happening at the sound source when higher or lower notes are produced. We decided to shorten the stick to make a scaled-up version of a shorter tine (which was making a note with a higher pitch) and compare its vibrations to those made when it was a longer tine (a lower note). We reduced the length of the wooden rod a bit (e.g., shorter by 10 cm) after we made some predictions to our original question: *What would the shape of the graph look like if we make a sound with a different pitch?* We used the motion detector and collected data from the different length wooden rods and noticed patterns: ● The amount of time it took for one wave to occur was less for shorter rods. ● We can see more waves across the same unit of time for shorter rods (e.g., five waves passed in two seconds, compared to three waves in two seconds for a longer rod).  In discussing various features in all the graphs, we argued that we needed a way to refer to two features that revealed important patterns: ● We argued that we needed a way to refer to the distance between a high point and the next low point, because it was sometimes changing and sometimes staying relatively constant. We agreed to refer to this characteristic as the amplitude of the wave. ● We decided we needed a way to refer to how often the waves were repeating, because that was sometimes changing and sometimes staying relatively constant. We agreed to refer to this characteristic as the frequency of the wave (more frequent waves are ones that occur more often, less frequent ones occur less often). We used the graphs of the wooden rod motion as evidence from both lessons to argue the following two points: ● The amplitude of the vibration cycle/wave increases as the sound gets louder. **(DCI: A simple wave has a repeating pattern with a specific . . . amplitude.) (MS-PS4-1)**

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		causing a sound source to vibrate with a greater amplitude produces a louder sound (effect), and how causing a sound source to vibrate at an increased frequency produces a higher pitch sound (effect).	• The frequency of the vibrations changes as pitch changes. Higher pitch sounds come from sound sources that are vibrating more quickly. **(DCI: A simple wave has a repeating pattern with a specific . . . frequency.) (MS-PS4-1)** We updated our model (see diagram above) to show some important cause and effect relationships. As we took stock of our updated model, we realized that although we feel we have figured out the answers to some of our questions about *how different sounds are produced (different sounds are produced from differences in the way the sound source vibrates), we haven't agreed on a way to explain how the sound gets from a sound source to our ears.* **Next steps: We think we can apply what we know to any new phenomena where sound is being produced to explain what is happening at the sound source for different kinds of sounds, and we agree to reassess our understanding with a new phenomenon in our next lesson.**

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This Lesson....What we are doing now: This lesson marks the end of Bend 1. You will help students connect three ideas together to go back and explain the anchoring phenomenon in further depth than they last did in Lesson 3. They will revisit one of the two previous data sources (video of song playing or the homemade needle and record) and will simulate the interaction of the needle and the record surface using manipulatives. They will use these results to make claims for how the different patterns in the grooves could force the needle to deform a different distance and vibrate at different frequencies. Last of all, students will take an embedded individual assessment applying what they learned to explain new phenomena.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L7: How can so many different sounds be coming from the needle and the record when you spin it? **(Includes Embedded Assessment #2)** <u>3 periods</u>: (40 min each) *Building toward* *<u>NGSS PEs</u>:* *1-PS4-1* *4-PS4-1* *MS-PS4-1*	The anchoring phenomenon from Lesson 1 A harp player in a video is plucking strings of different lengths and different sounds are heard coming from it.	**Argue from evidence** by respectfully providing and receiving critiques about each other's claims, explanations, models, and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail *to help explain how the variation in the patterns in the structure of the grooves on the record could force (cause) the needle to vibrate at different frequencies and with different amplitudes, resulting in it (effect) producing different sounds as you spin it.* *The embedded assessment #1 also targets a subset of the Lesson Performance Expectations from lessons 2 through 6.*	We wondered how the ideas we had developed so far might be used to explain how the needle produces so many different sounds. We had some predictions that the variation in the patterns in the bumps or shape of the grooves on the record might be forcing the needle to vibrate at different frequencies and amplitudes, so we wanted to look at one of these two data sources we had seen before to see if we could see evidence of this: (1) the Michael Jackson video of the closeup of the needle on the record, and (2) our own homemade needle and record from the anchoring phenomenon. Based on our observations of one of these data sources and our ideas we developed so far, we argued from evidence that • high notes and low notes, quiet sounds and loud sounds were produced at different points along the record surface; • the needle must be vibrating at a greater frequency if it is producing higher pitch notes and lower frequency if it is producing lower pitch notes; and • the needle must be vibrating with a greater amplitude if it is producing a louder sound and a lesser amplitude if it producing a quieter sound. But it seemed much harder to clearly see changes in frequency and amplitude in the vibrations of the needle than when we had the motion detector. We decided a large scale object (like a ruler, a straw, or a coffee stirrer) could help us visualize this predicted motion of the needle as it interacted with the patterns in the grooves when the record was spun. We used a coffee stirrer and a photograph of the record surface grooves to simulate its motion as they interacted with each other. --- We argued from evidence from the results of the previous simulation that, "different sections of grooves could force the needle to deform different distances, and therefore move back and forth at different amplitudes as the record spins." We updated our Incremental Model Tracker to include these ideas: • Different patterns in the grooves can force the needle to deform different distances, and therefore move back and forth at different amplitudes as the record spins. • Different patterns in the grooves can force the needle to move or bend back and forth at different frequencies as the record spins. In light of the claims we had made so far, we predicted how spinning the record faster would affect the sounds produced, and we tested our prediction. ---

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			We individually assessed our understanding by applying the ideas we figured out to explain a new phenomenon (someone playing a harp) and analyzed new sets of vibration-related data in our Lesson 7 - Assessment # 1. **Next steps (Optional): After this assessment, we selected one of three enrichment activities that we were most interested in discovering more about. One, an interactive reading, was related to how humans produce sounds with their voices. The other two, investigations to collect data on at home, were about how changing the thickness or tightness of an object affects how frequently the object vibrates after being struck or plucked.**

Next Lesson....Where we are going: The next lesson marks the start of Bend 2. Students will look at another phenomenon (a truck stereo playing music very loudly) and a surprising effect: the movement of windows in a building across a parking lot. This phenomenon will problematize something about their model that they took for granted—namely what the thing was that traveled from the sound source to our ears, detectors, or any object far away. This will help motivate future lessons around questions regarding what is happening with the air (or any material) that sound travels through and what exactly sound is.

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Overview of Bend Two: *In Bend Two, students investigate their questions about how sound travels. After observing sound from a car shaking the windows of a storefront, students help to plan and carry out investigations with the goal of finding evidence to support or challenge their conceptions around how sound travels. Through the course of this second set of investigations, students seek to answer these questions:*

- *How does sound travel?*
- *How does sound move through different materials?*
- *What exactly is moving through the material?*

What students figure out: *By the end of Bend Two, students will have uncovered a great deal about the nature of sound itself, as well as the materials that sound moves through. These ideas include the following statements:*

- *Collisions between the particles that make up matter can transfer energy through that material.*
- *Sound is a pressure wave traveling through that material.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

MS. Waves and Electromagnetic Radiation		
MS-PS4-1	MS-PS4-2	MS-PS4-3

MS. Motion and Stability: Forces and Interactions	MS. Structure, Function, & Information Processing
MS-PS2-3 (partial)	MS-LS1-8 (partial)

MS. Energy
MS-PS3-5 (partial)

Key to storyline columns:			
Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	**Phenomena**	**Lesson Performance Expectation(s):** • **Blue bold font: Science and Engineering Practice** • Regular blue font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena/question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	**What We Figure Out** (CCCs & DCIs), *New Questions* and **Next Steps** • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we now have* • **Purple bold font: Our ideas for the next (or future) steps to pursue.**

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Previous Lesson….Where we have been: The previous lesson marked the end of Bend 1. Students connected the ideas from the first bend to explain the anchoring phenomenon in greater depth. They used previous data sources and results from simulation with manipulatives to argue that different patterns in the grooves could force the needle to deform different distances and vibrate at different frequencies, therefore producing a wide range of sounds. Students took an embedded individual assessment, applying what they had learned to explain new phenomena.

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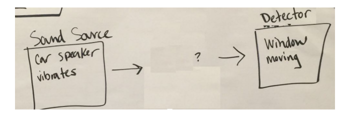
This Lesson….What we are doing now: Students will revisit the video of a stereo playing in a truck, but this time they watch the second half of that video clip and discover that the stereo is causing a window in a building across the parking lot to move. They will attempt to model this situation by showing what is occurring in the space between the sound source and the window. You will use differences in these models to motivate the need to investigate this aspect of the model further (related to what is actually traveling across that space).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L8: How does a sound source make something like this happen? 1 period: (40 min) S *Building toward* ⬇ *NGSS PEs:* *1-PS4-1* *4-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	When music is played very loudly from the stereo of a truck, it appears to cause a window in a building across the parking lot to move.	**Develop and use a model** to describe unobservable mechanisms *at work* in the space (traveling) *between a sound source (a stereo speaker in a truck) and another object at a distance (a window in a building across the parking lot) that helps explain what is* causing *the window to move* (effect).	We argued that our model from Bend 1 should apply to any sound-related phenomenon. We tested that claim by looking at another phenomenon of blasting music coming from a stereo in a truck and argued that it should predict and explain what is happening as the truck speakers produce these different sounds. We then watched the second half of the video clip; as the camera panned out from the truck playing this loud music, we noticed some interesting patterns: ● A window in a building across the parking lot from the truck appears to move. ● Some portions of the song appear to make these truck parts and the window move even more.  We argued that the sound caused the window far away to move. We developed a model to try and explain how this happens. This led us to realize that there was something we hadn't explained in our model yet: *What does it mean exactly when we say "sound travels to"? What is it that travels from here to there? When we say the vibrating object produces sound, what does that mean? How does a vibrating object produce a thing that travels from one place to another?* We wondered: *What is going on between the sound source and the window that can help explain how it is possible that a wiggle or vibration at the sound source could cause something (the window) far away to move?* We individually created models to try and answer this question. We shared our models in a gallery walk and jotted down new ideas and questions that these models raised to help answer the question: How does a vibration actually make something far away move? All of the differences we saw in the models raised more questions: ● *Is sound its own essence and maybe the air is carrying it across?* ● *Is the air being pushed to the window? Is the air moving at all?* **Next steps:** Because we want to figure out, *"Is the air being moved from the sound source to the window when sound is being produced?"* **we started brainstorming ways to go about investigating that question.**

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This Lesson....What we are doing now: You will help students test the idea that air from the sound source is traveling to the window or our ears by placing a sound source in an airtight container and testing whether the students can still hear it. They will also record the mass of the container before and after it produces sound. The results from this investigation will provide evidence that no air is moving all the way from the sound source to our ears (or window) when sounds are produced.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L9: When I hear a sound, is the air being moved from the sound source to my ear? 1 period: (40 min) *Building toward* *NGSS PEs:* *1-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	A cell phone is put in a container (ziplock bag or a plastic container with a tight-fitting lid). The phone is called and a sound is still heard. This container (along with the cell phone and the air within the container) is weighed before and after the phone is called and it makes ringing sounds that we can hear outside of the container. The scale reveals no change in mass.	**Planning and Carrying Out Investigations:** Conduct an investigation and revise the experimental design to produce data to serve as the basis for evidence to *test whether* air was moving from the sound source to the sensor (systems and system models). **Engaging in Argument from Evidence:** Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute *that the* air is not being moved (cause) all the way from the sound source to my ears when I hear the sound *or when the window moves* (effect).	We had some ideas for testing whether the air was moving from the sound source to the window (or our ears). These ideas all included some way of blocking the air. So we put a cell phone in a container (a ziplock bag or a plastic container with a tight-fitting lid) and played music from it and we could still hear it. We started to argue that this shows air isn't moving from the sound source all the way to our ears when we hear it, because the air is trapped in the container. But that seemed weird. *How were we able to hear it then? Are we sure no air came out? How do we really know that no air or stuff came in or out?* Some students suggested there could be a small leak. Thia raised an interesting issue regarding how we know whether a container has or hasn't leaked air. We thought of some possible ways to test whether any air got in or out of the container. One idea that we came up with was to put a sound source in a tightly sealed container and mass it before and after it makes a sound. We conducted the investigation and noticed patterns: • No air appeared to escape from the container, but we still could hear a sound. • The mass of the container and cell phone didn't change after it made a sound. We updated our model to show that no air was moving out of the container. As we looked at the model further, we wondered *if the air was even needed inside the container because even the sound was moving, the air wasn't*. This led to some different predictions as well as some ways we could test those. **Next steps: We want to try and remove air from the container and try to replace the air in the container with something else (like water).**

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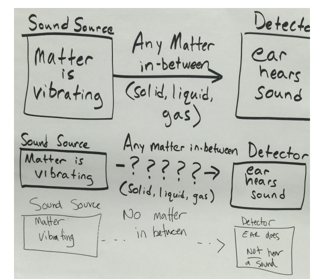
This Lesson....What we are doing now: You will help students test whether air is even needed to hear a sound through two investigations. One investigation you will do with the class will provide evidence that sound will move through any type of matter; while the other investigation will provide evidence that sound can't move across empty space that has no matter in it (a vacuum). These findings will support the claim that sound needs a medium (gas, liquid or solid) to travel through.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L10: Do we even need the air to hear sound? 1 period: (40 min) S *Building toward* *NGSS PEs:* *MS-PS4-1* *MS-PS4-2*	A video of a cell phone, which is playing music and is hung on a string inside an airtight container (bell jar) so it is touching nothing (except the surrounding air and string), shows that music can still be heard outside of the container. When a vacuum pump is hooked up to the container and turned on, almost no sound is heard after about 30 seconds. When the valve to let the air back in is opened, music can be heard from the cell phone again on the outside of the container. When you strike two golf balls or rocks together underwater in a fish tank and put your ear up to the glass, you and the person next to you can hear the sound.	**Plan and Carry Out an Investigation:** Conduct an investigation and revise the experimental design to produce data to serve as the basis to *test whether air was moving from the sound source to the sensor (systems and system models).* **Engage in Argument from Evidence:** Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute *that the air is not being moved (cause) all the way from the sound source to my ears when I hear the sound or when the window moves (effect).*	We had two ideas for investigations that could help answer our question. One idea was to use something to take all the air out of the container (suck it all out). The other idea was to fill the container that the sound source was in with something other than air (like water). For the first idea, we realized we needed some kind of special pump or something to make sure we got all the air out. We wanted to see what would happen if we used something like this when we put the cell phone in a container and pumped out all the air and then called the phone. For the second idea, we realized we could put the sound source in a container of water. Even though some of us had waterproof phones, we didn't want to risk damaging those phones. So we decided to collide two objects together in a container filled with water (e.g., two golf balls or rocks in water in a fish tank) and put our ears up against the side of the tank. Based on the results of our two investigations (or from analyzing a video of students doing them), we noticed patterns: ● As we took air out of the container, the sound became harder to hear. ● When we let air back into the container, the sound became easier to hear. ● We could hear the collision of the golf balls or rocks underwater, even though we were outside the water. This led us to argue from evidence that you need matter to move the sound across the space that matter occupies, and sound can move through any state of matter: solids, liquids, and gases. We showed this in our revised model pictured here:  This raised a new question for us: *Why would vibrations from a sound source be able to send sound traveling through a solid, liquid, or gas, but not through empty space?* **Next steps: We decided we needed to try and model what makes something a gas, liquid, or solid and how that is different from empty space.**

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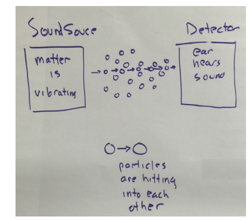
This Lesson....What we are doing now: Students will develop a model of what all states of matter have in common. This model will include particles, empty space, and motion. You will help students simulate what happens in the surrounding matter as a vibrating object is interacting with it. This model will suggest that motion (or energy) might be transferred through the medium from one end to another through particle collisions. This model will motivate the need to explore a simulation of this system where the frequency and amplitude of the sound source can be changed, and the particle collisions across the medium can be inspected more closely.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L11: How can we model the matter that sound travels through? 2 periods: (40 min each) S *Building toward* ⬇ *NGSS PEs:* *1-PS4-1* *5-PS1-1* *MS-PS4-2* *MS-PS3-5*	Previous phenomena related to sound traveling through a tank of water, a glass window, and air.	**Develop and use a model** to describe unobservable parts *(particles) of the system and how they would interact with each other in any state of matter to transfer energy through collisions between one another across a medium from a vibrating sound source.*	We developed models of the things that sound can travel through: water, glass, and the air. We agreed on the characteristics that solids, liquids, and gases have in common: ● Solids, liquids, and gases are made of particles moving through empty space, with different spacing in each state of matter. There is a great deal of space between particles in a gas, less space between particles in a liquid, and even less space in a solid. ● Particles can bump into and off each other in a solid, liquid, or gas. With these elements of the model agreed upon, we then wondered: *What happens to particles that the sound source is vibrating back and forth against (e.g., water or air)?* We wanted to simulate this using people as particles of the medium to try to figure this out.  When we simulated this, we further developed the model to reflect our current thinking: ● A vibrating source could push particles in the medium it is next to. ● Those particles transfer energy to other particles when they collide or bump into each other. ● If a push is transferred into the particles at one end of the medium, it might result in a cascading series of collisions between neighboring bands of particles across the medium. We decided we could use this model to explain the results from our earlier investigations: *Why can we hear a sound through a gas, liquid, or solid even though the matter doesn't move all the way from the source to our ears, and why can't we hear a sound through empty space?* **Next steps: We brainstormed what we wanted to include from our discoveries in a computer simulation to use next time to help us investigate further how sound travels across a medium such as** ● **things we want to be able to adjust about the sound source;** ● **the sort of particle interactions we want to include; and** ● **the sort of things we want to be able to visualize.**

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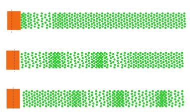
This Lesson....What we are doing now: Students will run a computational simulation exploring how particle collisions propagate across a medium from a vibrating sound source. Their investigations will help them develop complementary models for the nature of the wave traveling across the medium, including a particle density model (bands of dense and less dense batches of matter), a transverse wave model (density vs. time at a given location), and a ray model (showing the direction of energy transfer across the medium).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L12: What exactly is traveling across the medium? 2 periods: (40-45 min each) S *Building toward* ⬇ *NGSS PEs:* *1-PS4-1* *4-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	A computer simulation (Netlogo) provides a way to visualize and collect data on particle packing (density) at a point in space as sound travels through it over time, as well as on what happens across a region of space over time. 	**Use mathematical and computational thinking** to generate data for unobservable mechanisms (*propagation of sound waves across a medium to investigate and describe the patterns in the motion (energy) of each single particle (matter) in the medium, the changes in particle density in a given space (pressure) over time, and the changes in particle density bands (pressure) across the medium (system) that result from changing the frequency and amplitude of vibrations at the sound source*.)	We brainstormed things we wanted to see included in a computer simulation that could help us better understand how sound travels across a medium. These included the things we would want to be able to adjust about the motion of the sound source in that simulation and the sort of particle interactions in the medium we thought would need to be included. We argued that such a simulation would help us better visualize, explore, and understand what is going on. So we conducted two investigations using a computational simulation (NetLogo) that had the objects and interactions we defined as necessary parts of the model. Based on the data we collected during these investigations, we determined the following: • When an object moved back and forth, it produced bands of compressed and expanded particles that traveled through the medium. • The density of compression was greater when the amplitude of vibration at the sound source was increased. • The distance between compression bands appeared to change when we changed the frequency of vibration. • After the wave passed through a region in the medium, the density of particles in that region returned to what it was before the wave arrived. We produced a three-frame, time-lapse model to make arguments for evidence to answer the original question: What exactly is traveling across the medium? We made these points: • An object that is vibrating pushes into and pulls away from the medium next to it. • This leads to a pattern of bands of "more/less densely packed particles" being produced in the medium. • Collisions between the particles in the medium result in these bands moving away from a sound source. • We can represent the direction of the resulting energy transfer across the medium using rays (or arrows). . **Next steps: We think we can apply what we know to any new phenomena where sound is being produced to explain things like (a) how you can hear sound through water and (b) what makes the window shake when the stereo speaker is playing. We try and apply the ideas we developed in this lesson to revising our model for explaining the stereo speaker phenomenon again.**

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This Lesson....What we are doing now: This lesson marks the end of Bend 2. You will help students develop a Gotta-Have-It checklist to use for models and explanations related to phenomena where a sound source causes something far away to move. Students will take what they have learned from the unit thus far, and in small groups, develop a model to explain a new phenomenon: why salt on plastic wrap stretched over a bowl jumps up and down when a drum far away is hit. They will then apply the same checklist to revising their model and explanation for why the window across the parking lot moved when the truck stereo was blasting music.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L13: How does matter around us make sound move? (Includes Embedded Assessment #3) <u>2 periods</u>: (40-45 min each) S *Building toward* *<u>NGSS PEs</u>:* *MS-PS4-1* *MS-PS4-2*	All previous phenomena. When a drum was struck, a sound was made, and then the salt on a piece of plastic wrap stretched over a bowl jumped up and down.	**Develop a model** to describe phenomena using unobservable mechanisms *for how banging on a drum causes vibrations on it that lead it to produce sound, which causes particles of matter in the surrounding medium to be compressed and expanded together, which then collide with neighbors to transfer energy across the medium to result in (effect) making salt on plastic wrap stretched over a bowl far away move.* **Develop and use a model** to describe phenomena using unobservable mechanisms *for how a stereo speaker playing music could cause vibrations that produce sound (effect), which causes particles of matter in the surrounding medium to be compressed and expanded together, which then collide with neighbors to transfer energy across the medium to result in (effect) making a window far away move.*	We shared what we thought was tricky about trying to develop a model to explain how the music from the truck stereo traveled to the windows and made them move, and we shared what we were still stuck on. In order to help us out, we brainstormed some other experiences we've had where it seemed like sound was making something move far away from the sound source. We argued that whatever explanation we develop for the more general question, "How does a sound source cause sound to be produced AND how can that sound then cause something far away to move?" needs to explain the truck stereo and window as well as many of these other related phenomena. We explored another related example—banging on a drum caused salt sitting on plastic wrap stretched over a bowl to jump up and down. We took stock of which ideas would be needed to explain both (a) the drum and the salt phenomenon and (b) the truck speaker and the window phenomenon and made a Gotta-Have-It checklist out of these. In small groups, we used this list to develop a model to explain the drum and salt phenomenon. Comparing our models led us to identify some additional ideas that were common among the models: • Energy is put into the system by a force applied to the sound source. • Larger forces lead to further deformation of the sound source, which leads to vibrations of bigger amplitude. • These cause matter in the medium to go through bigger changes in the amount it is compressed and expanded (bigger changes in density). • This leads to more energy being transferred across the medium through the subsequent chain of particle collisions that occur through the back-and-forth motion of the particles in the medium. **Next steps: We took our Gotta-Have-It checklist and went back to try to apply it the question, "How did the stereo speaker make a sound, and how did that sound make the window move?" as our end of Bend 2 assessment.**

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Bend 3 of the Storyline Narrative:
How Can We Sense So Many Different Sounds from a Distance?

Overview of Bend Three: *In Bend Three, students complete their journey from the sound source to the detector. Students begin by studying the composition of the inner ear and how hearing works. They also investigate lingering questions about the detection of sound, and why sound behaves in some of the strange ways that it does. Throughout the course of this third set of investigations, students seek to answer these questions:*

- *How can we detect sound?*
- *Why do sounds get quieter the further I move from the source?*
- *What structures can we design to make sounds louder?*

What students figure out: *By the end of Bend Three, students will have a complete model of how sound is created, how it travels, and how it is detected. They will develop this final understanding by discovering more about how sound is detected, and how sound behaves when it meets the boundary between two different materials. These ideas include the following statements:*

- *Sound can make matter vibrate; different structures in our ear vibrate in response to different sounds and transmit signals to our brain through nerve cells.*
- *The patterns of these vibrations can be encoded in either a digital or analog form.*
- *Sound can be tracked as energy flows through a designed or natural system.*
- *When a wave meets a surface between two different materials or conditions, part of the wave is reflected off that surface and another part continues on.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

MS. Waves and Electromagnetic Radiation		
MS-PS4-1	MS-PS4-2	MS-PS4-3

MS. Motion and Stability: Forces and Interactions	MS. Structure, Function, & Information Processing
MS-PS2-3 (partial)	MS-LS1-8 (partial)

MS. Energy
MS-PS3-5 (partial)

Key to storyline columns:

Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	Phenomena	Lesson Performance Expectation(s): • **Blue bold font: Science and Engineering Practice** • Regular blue font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena/question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	**What We Figure Out** (CCCs & DCIs), *New Questions* and **Next Steps** • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we now have* • **Purple bold font: Our ideas for the next (or future) steps to pursue**

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Previous Lesson....Where we have been: This lesson marked the end of Bend 2. You helped students develop a Gotta Have It checklist to use for models and explanations related to phenomena where a sound source caused something far away to move. They used this list to construct a model and explanation for a new phenomenon: why salt on plastic wrap over a bowl jumps up and down when a drum is hit far away. Individually, students applied this checklist to revising their models and explanations for why the window across the parking lot moved when the truck stereo was blasting music.

This Lesson....What we are doing now: This lesson marks the start of Bend 3. Students will have unanswered questions regarding how our ears detect sounds. After watching a video tour through the human ear and reading some information, they will reconstruct the pathway through which energy is transferred from the ear to the nerve cells that send signals to the brain. They will also gather information from an out-of-class reading about the causes of hearing loss.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L14: What is going on inside my ear that can explain how we can detect certain sounds? 1 period: (40-45 min) S *Building toward* *NGSS PEs:* *1-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5* *MS-LS1-8*	An otoscope video of an eardrum examination by a doctor shows structures in the ear canal. Information from experts about the inner ear describing functions of the cochlea and hair cells is provided through an adapted reading. Other media sources are as follows: • Animated diagram of vibrations entering the inner ear • Video of Cochlear Animation with narration that explains tonotopic arrangement and vibration of basilar membrane • Video of Deafening Sound—How Hearing Works showing stereocilia vibrating	**Obtain and communicate information** combined from written text and video into visual displays *showing how the structures in the ear interact with each other to transfer vibrations (cause and effect) from the eardrum to fluid in the cochlea and to a series of sensory cells along this structure that then vibrate (more or less) in response to vibrations of particular frequencies, thereby sending signals along different nerve cells to the brain in response to different pitch sounds.*	We brainstormed possible things that might be happening inside our ears, and we have heard that there is an eardrum inside the human ear. Maybe there is a structure that moves like the window does. We wanted to check this out. We explored this by watching a video taken through an otoscope by an ear, nose, and throat (ENT) doctor, and we discovered that the eardrum looks like a drum membrane and also moves and is pulled tight when it works. This led us to claim that the eardrum would move like a real drum would if sound reached it. But then we started to wonder what happens next to these vibrations after they reach the eardrum and whether there is anything else behind this eardrum that might help explain how sound is detected. We gathered evidence from a reading (and video clips) developed with support from an ENT doctor and a neurobiologist, which we organized into an annotated diagram of the inner ear structures showing the following: • Vibrations are transmitted from the eardrum to tiny bones in the ear and then to a structure called the cochlea. • The cochlea contains fluid that transfers vibrations along the basilar membrane, which has different areas that correspond to where different pitch sounds are detected. • All of these areas contain stereocilia (hairs attached to sensory cells) that deform and vibrate more or less in response to different pitch sounds. • When a stereocilia is bent far enough, the cell it is attached to sends a signal to a nerve cell that relays it to the brain. • Hearing loss is caused when one of the structures in the ear is damaged. This damage can be irreversible if the hair cells or their detectors, the stereocilia, are permanently damaged. One thing this made us question (for classes that will be doing Lesson 15) was: *What types of sounds might be the most dangerous to the structures in our ears—louder sounds (greater amplitude) or sounds of a higher pitch (greater frequency)?* **Next steps (in home-learning reading): We want to gather additional information related to how other creatures hear and why some creatures can hear things we can't (different structures).**

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This Lesson....What we are doing now: Students plan an investigation to answer the question: What transfers more energy to an object—doubling the amplitude or doubling the frequency of a sound wave? Then students will take the results of their investigations to develop a mathematical model to argue that the amount of energy in a wave is directly proportional to the frequency, and the amount of energy in a wave is proportional to the square of the amplitude.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L15: What transfers more energy—waves of bigger amplitude or waves of greater frequency? 2 periods: (40 min each) *Building toward* *NGSS PEs:* *1-PS4-1* *4-PS4-1* *MS-PS4-1* *MS-PS4-2* *MS-LS1-8*	A bamboo skewer stick used to simulate vibrations from a sound source, marble(s) used to simulate particles in the medium, and a marker used as a target for the vibrations to push against provide evidence of energy transfer to the marker (sled) based on how far the sled is pushed across the table. 	**Plan and Carry Out an Investigation:** Identify what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to determine *what* transfers more energy—waves with greater amplitude or waves with greater frequency. **Use Mathematical and Computational Thinking:** Apply mathematical concepts and processes to scientific questions about *what* transfers more energy—waves with greater amplitude or waves with greater frequency.	We saw that stereocilia get knocked over when damaged. We learned in the previous reading that louder or higher frequency sounds can be more damaging. We gave examples of times we have seen waves knock things over. One example we gave was sandcastles at the beach. We argued that more frequent waves or higher amplitude waves would certainly transfer more energy to the sandcastles to wash them away more quickly. This led us to wonder: *What transfers more energy to things like sandcastles at the beach—waves that come at a higher frequency (more often) or waves that come at a higher amplitude (bigger waves)?* We argued that there is a similar question related to our compression wave model: ● Louder sounds are produced by sound sources that deform with a bigger amplitude in pressure; so if they deform more, they will squash more particles closer together. Therefore, the sound waves would have higher particle density in their band peaks, which would lead to harder pushes on the eardrum, which would transfer more energy. ● Higher frequency sounds are produced by sound sources that deform back and forth a greater number of times in a given time period. More sound waves would be generated, and each sound wave would push on the eardrum, which would transfer more energy because of the increase in pushes. But this raised a question: *What would transfer more energy to our eardrum or to the storefront window—doubling the amplitude of a sound wave or doubling the frequency?* We made some predictions and had different ideas. We identified parts of the system that we wanted to include from our previous models as well as a way to measure the energy transferred to an object. This included: ● a sound source that we can pull back a different amount each time (to simulate creating different amplitude waves); ● a medium of particles we can transfer the energy into; and ● a device to absorb the energy transfer and measure it. We mapped these elements to the objects in the experimental setup the teacher provided. We began by trying out the device to see how we could pull the stick back and launch a marble to represent a single back-and-forth vibration of the sound source pushing on the particles in the medium and to see the effects on how far the marker (sled) is pushed. We tried it three times to see how reliable the results were from one trial to the next. Based on these results, we argued that we should try to do three to five trials for each level we test in each investigation. As a class, we planned how we could use this device to conduct the first investigation on the effects of more compression waves in a given time period. We collected data from our first investigation, calculated averages, compared our results, and noticed some patterns: ● Doubling the number of waves produced in a time period pushes the sled about twice as far. ● Tripling the number of waves produced in a time period pushes the sled about 3 times as far.

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			● Quadrupling the number of waves produced in a time period pushes the sled about 4 times as far. We argued that this makes sense. Because each wave in the series has the same frequency, it would transfer the same amount of energy, and this relationship should be directly proportional. We then made predictions regarding whether the same relationship would hold true for doubling, tripling, or quadrupling the amplitude of the wave we produced. We modified our procedure to conduct this second investigation. After we collected our data and made our calculations, we noticed some patterns: ● Doubling the amplitude of waves produced pushes the sled about 4 times as far. ● Tripling the amplitude of waves produced pushes the sled about 9 times as far. ● Quadrupling the amplitude of waves produced pushes the sled about 16 times as far. We developed a mathematical model to argue that the amount of energy in a wave is directly proportional to the frequency of the wave, and the amount of energy in a wave is related to the square of the amplitude of the wave. In our home-learning for Lesson 15, we have figured out: ● how hearing works in general (L14); ● how other creatures hear different things than we do (L14 home-learning); and ● how energy transfer from louder and higher frequency sounds can lead to hearing loss (L15). We also know that when there's been damage to certain portions of the cochlea, the structures in that region can no longer convert movement energy to electrical energy (impulses) in order to send signals along nerve cells to the brain. This damage leads to hearing loss. **Next steps: We are now wondering if things like hearing aids and microphones have similar structures and functions as a working ear. We want to investigate that during our home-learning.**

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Bend 3 of the Storyline Narrative:
How Can We Sense So Many Different Sounds from a Distance?

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This Lesson....What we are doing now: Students collect data about the patterns they find when standing at different points around a sound source. You will guide your students to draw a model to represent their findings as a class. The model has an issue to be resolved: How can we use our model to explain why the sounds are getting quieter and the amplitude is decreasing? We revise our models to answer this question. This makes us start to wonder if spreading sound out causes the amplitude to decrease, is there a way to scoop it back together?

<table>
<tr><th>Lesson Question</th><th>Phenomena</th><th>Lesson Performance Expectation(s)</th><th>What We Figured Out (CCCs & DCIs), New Questions and Next Steps</th></tr>
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L16: Why do sounds get harder to hear the farther away I am from their sources?

Option A:
2 periods:
(40 min each)

Option B:
1.5 periods:
(45 min + 15 min)

S

Building toward

NGSS PEs:
1-PS4-1
4-PS4-1
5-PS1-1
MS-PS4-1
MS-PS4-2

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Our ears (and a sound detection app) provide evidence of whether the volume and/or frequency of a sound changes based on how far away we are from the sound source. (The sound source is a computer or phone playing a tone via an online tone generator.)

(optional) Dropping a single marble into a tightly packed cluster of marbles shows how collisions spread outward from a single point over a greater number of particles (marbles) so that particles near the edge get pushed barely at all compared to marbles closer to the point of impact.

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Plan and Carry Out an Investigation identifying what tools are needed to do the gathering, how measurements will be recorded, and how much data are needed to determine patterns in how the distance from a sound source affects the amplitude and frequency of a sound detected at a microphone.

Develop and use a model to show the relationships among variables (patterns of particle density and energy/amplitude of a sound wave) including those that are not observable but predict observable phenomena.

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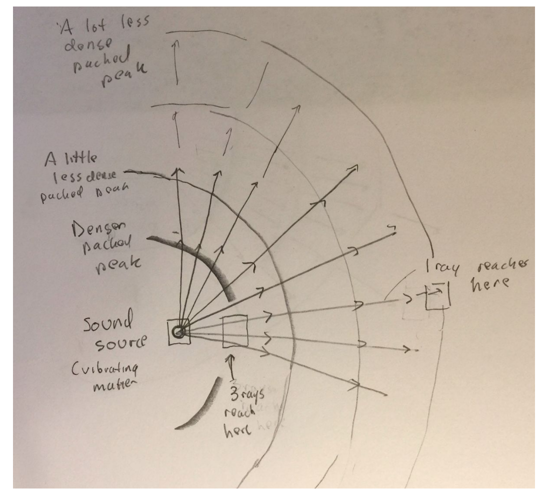
We checked our Driving Question Board and our initial patterns in the phenomena, and we realized we still had some questions about why sounds seem louder the closer we are to the source. We decided to investigate this further. We collected data on this using our ears and keeping our eyes closed.

We noticed some patterns:

- The farther away we got from the sound source, the quieter that sound got, but the tone/pitch didn't seem to change. We then verified this using a sound detection app.
- We could hear the sound in any direction from the sound source (and it seemed to remain the same volume) as long as we stayed at the same distance from it.
- We could get far enough away from the sound source that we couldn't hear the sound anymore.



We developed a class model representing what we know from the evidence:

- We know the sound travels in all directions, so the compression bands in the medium must travel outward in all directions from the sound source (we showed this with arrows and dark circular bands).
- This meant that the sound waves and energy radiate away from a source (we showed this with arrows and dark circular bands).
- The frequency of the wave wasn't changing as we got farther away from the sound source (we showed this by keeping the dark circular bands equidistant from one another).

But we realized a limitation to our initial radiative model. It doesn't have a way of representing that the amplitude of the wave is decreasing the farther away we got from the sound source. We thought this must be happening, because that is the only way to account for the decrease in volume with distance.

We revised our radiation model to represent this by showing a lighter and lighter semi-circle the farther we are from the sound source, and this represented a compression band of less and less particle density (less amplitude). This represented what the matter was doing. We also still included arrows showing the direction of the energy of the wave. We evaluated this model and summarized that

- as the number of rays decreased in a given area, the amount of energy in that area decreased; and

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			• when we drew this and counted the number of rays in "squares" farther from the sound source, we realized there must be less sound energy reaching each square farther away. The amplitude of those waves got smaller the farther away they traveled from the sound source. We think that waves of lower amplitude have lower energy, which is why the sounds became quieter the further we are from their sources. We revised our consensus model from the end of Bend 2 to simplify it a bit more: • We represented the direction of energy transfer across the medium and how the amount of energy that reached a spot decreased with distance by using rays (or arrows). • We represented the amplitude changes as pressure bands that were becoming less dark (less dense) the farther away they radiated from a sound source (but this seems rather hard to draw, so we thought we might try sticking with the ray model more and only come back to this other representation if we need it). We thought back to our anchoring phenomenon of the record and needle, and ways to hear people talking from far away. This led us to wonder: • *Does the orientation of our hands near our ears affect these waves?* • *Are there ways to channel or redirect the energy of a wave so that it doesn't spread out as much*? **Next steps: We think maybe certain barriers (like a cone) or your hand cupped a certain way can redirect waves, and we want to investigate the idea that there may be different materials and different structures we could use to redirect, amplify, or dampen the energy of waves.**

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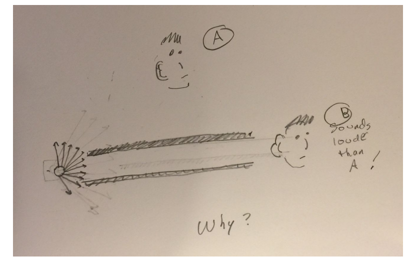
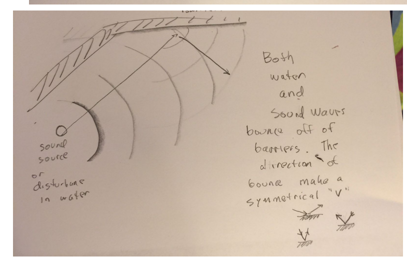
This Lesson....What we are doing now: Students design a device to channel sound using various shapes made with paper and tape. They will use their findings from testing this device to explain why some shapes work better than others, arguing that sound bounces off walls of the object. They conduct an investigation to determine that sound waves bounce off objects with smooth surfaces at predictable angles.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L17: Can I scoop sound back together or prevent it from spreading out in order to make it louder? 2 periods: (40 min each) S *Building toward* *NGSS PEs:* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	A very quiet sound source (a ticking watch) placed at one end of a long tube or cone at X centimeters sounded louder than listening to the sound source at the same distance or even a little bit closer without the tube or cone. When we place the same sound source so that one tube points toward a gap in the wall, we can adjust the angle of another cardboard tube on the other side of the gap in the wall to determine if there is an angle at which we can hear the ticking sound (and if so, hear it louder than at other angles). 	**Design a solution:** Apply scientific ideas to design, construct, and test the design of an object (a structure) *that amplifies the volume of a sound from a sound source at a given distance and evaluate how it functions.* **Develop and use a model** to describe unobservable mechanisms to explain *how it's possible that certain shaped tubes and cones* (structures) make a sound louder than without the tube or cone (function).	We thought that the shape of some objects can keep sounds from spreading out and maybe make them louder, so we wanted to investigate that more today. We used paper and tape to make tubes and cones to test this idea and conducted some investigations. We noticed a pattern in our data: When we placed a tube or cone at the source of a sound and we listened at the other end of that tube or cone, the sound seemed louder than it did if we remained at the same distance from the sound, but didn't use a tube or cone.  We brainstormed other examples of where this might be happening. We constructed explanations of how that would work—somehow the waves are being redirected or prevented from being spread out. We shared our ideas to show what we think happens to the rays as they spread out and hit the walls of the devices in use and proposed some possible alternate models: • Maybe the sound waves bounce off the surfaces of the object. • Maybe the energy is channeled or redirected when the particles hit the inner surface of the cone or tube. • Maybe it is like a ball bouncing off a wall. • The sound seems louder when we listen to it through the tube, but it sounds a little jumbled.  This led us to wonder *what exactly happens to waves when they reach a barrier or surface like a wall*. We made some predictions about what would happen if we directed a sound wave at a flat wall through a paper tube at different angles. We had lots of different predictions about whether the sound would bounce off the wall and if there was any pattern to how the sound might bounce off the wall. We conducted an investigation and noticed some patterns: • There was a certain angle at which the sound was loudest. • There was a relationship between the angle at which the sound was loudest and the angle of the tube with the wall. We argued that we can apply these findings to explain why the tubes and cones made the sound louder. We developed a model to represent what we think is happening.

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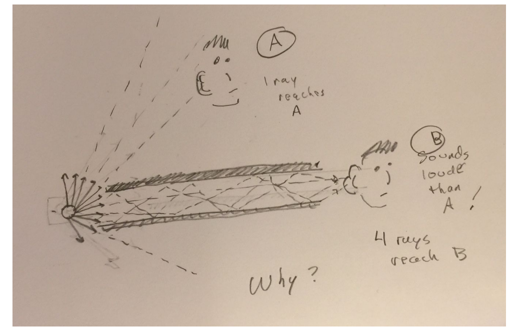
We applied that model to our original results and the anchoring phenomenon to explain why people in front of the cone heard the sounds better than those behind it. Also, this model might account for why the sound traveling through the tube could sound a bit jumbled. This is because some of the sound waves might be bouncing off the inner walls of the tube, while other sound waves don't hit the walls and travel straight through the tube.

We argued from these examples that

- smooth surfaces tend to bounce waves off in a symmetric V pattern (reflection); and
- the shape of some structures (e.g., tubes, cones, dishes) can redirect reflected sound waves so they head toward a detector.



We then used this evidence to develop a model to explain why holding a tube against your ear and pointing it toward the sound source causes you to perceive the sound as being louder than it would be without the tube. Our model also has to explain how the sound would radiate outward from its source without being reflected or directed to your ear if you were not holding a tube against your ear.

Next steps: Before wrapping up, we see some historical photos that demonstrate the principles of our model in application. This makes us wonder how early militaries used these concepts to hear sounds from a great distance, which we will read about during our home-learning.

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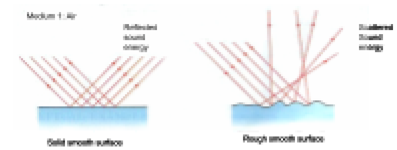
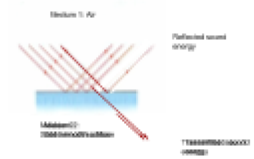
This Lesson....What we are doing now: Students evaluate a model that represents what happens when a sound wave reaches a boundary between two different media. They revise the model to account for an old phenomenon (hearing sound from a phone in a sealed container) to show that when a sound wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected of that surface and another part continues on (transmitted).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L18: If sound waves are reflected when they reach a barrier then how can we hear anything on the other side? 1 period: (40–45 min) S *Building toward* *NGSS PEs:* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	Two different stiffness/thickness Slinkies chained together show evidence of a compression wave reflecting back from the boundary between where the two springs meet and a compression wave going into and through the new second spring as well.	**Developing and Using Models:** Collaboratively develop a model based on evidence that shows the relationships between how much energy reaches a barrier, how much goes through it, and how much is reflected for frequent and regular occurring events (sound pressure waves).	We revisited one of the models we explored from our home-learning and used it to argue for why different surfaces (smooth vs. rough) could cause sound waves to bounce off them differently.  We revised this model based on a limitation we uncovered to show that some sound must be coming through the solid walls of the container in order for us to explain how we heard the cell phone in the closed container. We evaluated the model again and determined that while it showed the relative amounts of sound energy that are reflected vs. transmitted when sound waves reach a boundary between two materials, it didn't represent a microscopic view of what the matter in both materials was doing that could explain this phenomenon.  We analyzed the behavior of a single Slinky and then a chain of two Slinkys made of different materials to argue for how they could represent any springy material (solid, liquid, or gas) and could help us better understand the relationship between the matter in each medium and the energy transferred through it. After producing some compression waves both in the single spring and in the chain of two springs, we discovered some interesting patterns: • A compression wave moves through the medium, but the matter in one spot just moves back and forth. • Some of the energy is reflected and some of it is absorbed when sound reaches a boundary between two different media. We argued from this evidence and from the models we produced that when a sound wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected off that surface and another part continues on (transmitted). We observed a situation in which a drummer was playing a drum in a room that was producing too much echo. *We wondered if there might be materials that could be added to the room to decrease the echo by reflecting very little sound energy and transmitting very little sound energy through the walls.* **Next time: In our home-learning, we brainstormed some possible design solutions to compare in our next lesson.**

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This Lesson....What we are doing now: Students compare solutions for decreasing the amount of echo in a room and compare those to the solutions (results) that a drummer tried. They develop a model to support the argument that the addition of materials to the walls and ceiling of an empty room that don't reflect, scatter, or transmit sound energy would decrease the loudness of the sounds heard in the room and the loudness of sounds heard through the wall in an adjacent room. They explore a new phenomenon (bending the end of a paperclip back and forth) and uncover evidence of temperature increases occurring in the metal. They use this evidence to argue that the energy of the sound wave that is absorbed by some materials is converted to temperature increases in that material (increased random particle motion and increased thermal energy).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L19: What else happens to the energy of the wave as it travels through the medium? 1 period: (40 min) S *Building toward* *NGSS PEs:* *MS-PS4-1* *MS-PS4-2* *MS-PS3-5*	Bending the ends of a straightened paper clip back and forth leads to a temperature increase at the vertex of the U or V that we make with the paper clip.	**Engaging in Argument from Evidence:** Use oral arguments supported by empirical evidence and scientific reasoning to revise a model for a phenomenon (*when* matter moves [or is bent] back and forth, some of the energy of that motion is absorbed by the matter and converted to thermal energy).	We shared our design solutions for the drummer's room from our home-learning and saw various patterns across our solutions: • Many of us added materials in the room that aren't smooth to decreasing the amount of echo. • Some of us added materials we argued would absorb some of the sound energy. We wondered whether there were any materials that don't reflect or scatter much sound energy AND don't transmit it. We argued that if there were such a material, then the sound of the drum in the room wouldn't be as loud, and the sound in an adjacent room (through the wall) wouldn't be as loud either. After we watched more of the video, we analyzed the results of the design solutions the home drummer in the video had tried, and we saw some patterns in the solutions: • The material he hung on the wall had big bumps on it and the material looked like foam. • The more patches of this material he hung up, the less echo in the room there was when he struck the drum. • The sound of the drum was also a bit quieter in the room when more of these patches of material were put in the room. We developed a model to represent the behavior of this material (foam) that allows very little sound transmission. The model we developed raised new questions about what happens to the "missing energy" or the "energy that goes into the material." We argued that maybe the energy going into the material changes form or is somehow detectable. We decided we could try to detect it. We used a paper clip as a manipulative to explore this idea further. We plucked the paper clip and forced it to bend back and forth many times. We noticed patterns in the paper clip that led us to argue from evidence for these claims: • Some of the energy that goes into a material that is bent back and forth over and over again turns into a temperature increase. • The foam that the drummer added to his practice room is absorbing some of the sound energy and warms up. • Optional (for students who have developed a way of representing temperature and thermal energy related to the average speed of particle motion in prior instruction): The energy that is absorbed by the material results in an increase of the average speed of the particles in that substance (increasing the thermal energy of that object). **Next Steps:** Because we had lots of discoveries about what happens to the energy of a sound wave as it meets the surface between two different materials or conditions and what we mean by the energy "going into the object" or "getting absorbed by the object," we decided to make time to summarize all of these important discoveries in our Incremental Model Tracker at the start of the next lesson.

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This Lesson....What we are doing now: This lesson marks the end of Bend 3. You will help students build a consensus model and summary table of all the scientific principles they figured out over the course of the unit, and determine which of these would need to be part of an explanation for different phenomena and related questions that the class explored over the course of the unit related to: What causes different sounds? How do sounds move across a medium? Why is it easier or harder for some people to hear sounds in some places over others?

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**

L20: How can we explain our anchoring phenomena and which of our questions can we now answer? (Includes Embedded Assessment #4)
 	
3 periods: (40 min each)
 	
S
 	
Building toward
↓
NGSS PEs:
1-PS4-1
4-PS4-1
MS-PS4-1
MS-PS4-2
MS-LS1-8
	All previous phenomena.	**Develop and revise a model** to show the relationships between the components of the system (in the anchoring event) and their interactions, including how sound is generated, how it travels, and how it is detected to describe observable and unobservable phenomena.
		
		Construct an Explanation applying scientific ideas, principles and evidence to construct and revise an explanation for real world phenomena and events pertaining to how sounds get made, travel (energy), and get sensed?
			We added the key discoveries we made over the last three lessons to our Incremental Model Tracker and Gotta-Have it checklist.
			• L17: Sound waves radiate outward over a space from a source, leading to a decrease in amplitude (less particle density differences) the further from the source they travel.
			• L18: When a sound wave meets the surface between two different materials or conditions (e.g., air to water), part of the wave is reflected off that surface and another part continues on into the new media.
			• L19: When energy is transmitted through a medium, some of the energy may be absorbed by the medium and converted to thermal energy (e.g. traveling through air, solids, liquids, and the results of the paper clip)
			
			We built a summary table of all the science principles we think we need to include in explanations for questions related to:
			1. *What exactly causes different sounds?*
			  a. *Pushing on an object can deform it; deforming it can cause it to spring back and vibrate (four steps in our model).*
			  b. *Vibrating objects are sound sources.*
			  c. *Vibrations of different amplitude and different frequency can cause different sounds.*
			2. *How do sounds move from a sound source to our ears?*
			  a. *Particle collision → energy transfer*
			  b. *Compression and expansion of the matter*
			  c. *Density waves propagating through the medium*
			3. *Why is easier (or harder) for some people to hear sounds in some places over others?*
			  a. *Transmission—how the sounds get to your ear*
			  b. *Absorption by the ear detectors—how the ear works and hearing loss*
			  c. *Radiation—makes sounds quieter farther away due to the energy spreading out*
			  d. *Reflection—redirect (echo) some of the energy in the wave away or toward you*
			  e. *Absorption within the medium—makes sounds quieter the more energy is converted to thermal energy in the medium that it travels through to get to your ear*
			
			We took stock of the questions on the driving question board we feel like we can now answer, which included many (except for ones about electronic devices, which we may decide to investigate further (or not) in bend 4):
			• Why do different objects produce different pitch sounds?
			• Why does the truck speaker make the window move?
			• Why could we hear the sound through the water tank even though we were on the outside of it?
			• Why couldn't we hear the music when there was no air in the container the sound source was in?
			• Why can louder sounds lead to hearing loss sooner than softer sounds?
			• Why can higher pitch sounds lead to hearing loss sooner than lower pitch sounds?
			• Why does cupping your hand near your ear helps you hear sounds better?
			• Why do sounds get harder to hear the farther you are from their sources?
			• Why can we hear so many different sounds from the spinning record?

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			We took an end of Bend 3 assessment (developing models and constructing explanations), which we applied to explaining other sound related phenomena. **Next steps (optional): We will revisit our Driving Question Board to take stock and see that we still have unresolved questions relating to speakers and microphones. We agree that before wrapping up this unit, we want to take a quick detour and see how we can use what we've figured out to better understand how speakers and microphones work.**

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Overview of Bend Four: *In Bend Four, students extend their journey by continuing their investigation of related phenomena by taking apart and constructing their own speakers. This bend may also serve as an optional extension for interested students. Through the course of this third set of investigations, students seek to answer these questions:*

- *How do speakers (and microphones) work?*
- *What is inside a speaker that vibrates to make sound?*

What students figure out: *By the end of Bend Four, students will apply their understanding of how sound is made, how it travels, and how it is detected. They will explore the inner workings of speakers, and how the relationship between magnets and charged coils leads to the production of sound. These ideas include:*

- *Electric and magnetic interactions can cause the vibrations needed to replicate complex sound.*
- *Vibrations can be converted into electrical energy using magnets and vice versa.*
- *Electronic devices can sample the amount of electrical energy in a system and record it at different points in time as number values (digits) and use this information to reproduce the approximate pattern of change in electrical energy in the system over time.*
- *Digitized signals are a more reliable way to encode and transmit many forms of information (including sound) than non-digital signals (analog).*

NGSS PERFORMANCE EXPECTATIONS BUNDLE		
MS. Waves and Electromagnetic Radiation		
MS-PS4-1	MS-PS4-2	MS-PS4-3
MS. Motion and Stability: Forces and Interactions	**MS. Structure, Function, & Information Processing**	
MS-PS2-3 (partial)	MS-LS1-8 (partial)	
MS. Energy		
MS-PS3-5 (partial)		

Key to storyline columns:			
Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	**Phenomena**	**Lesson Performance Expectation(s):** • **Blue bold font: Science and Engineering Practice** • Regular blue font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena/question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	**What We Figure Out** (CCCs & DCIs), *New Questions* and **Next Steps** • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we now have* • **Purple bold font: Our ideas for the next (or future) steps to pursue**

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Previous Lesson….Where we have been: This lesson marked the end of Bend 3. You helped students build a consensus model and summary table of all the scientific principles they figured out over the course of the unit, and determined which of these would need to be part of an explanation for different phenomena and related questions that the class explored over the course of the unit related to: What causes different sounds? How do sounds move across a medium? Why is it easier or harder for some people to hear sounds in some places over others?

This Lesson….What we are doing now: This lesson will marks the start of Bend 4. This is an optional bend to pursue, if your students are interested in answering the questions they have about electronic devices that produce and detect sound and if you are targeting the digital vs. analog performance expectation (MS-PS4-3). You will help students explore how speakers work and how different amounts of electrical energy applied at different intervals can force the speaker to vibrate at different frequencies and amplitudes.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L21: Can a single object, like a speaker or a needle, really be forced to make all these different sounds? 1 period: (40 min) *Building toward* *NGSS PEs:* *1-PS4-1* *MS-PS4-3* *MS-PS3-5* *MS-PS4-1* *MS-PS2-3*	Previous truck speaker and window vibration video. Speaker deconstruction (optional). A video clip provides evidence of the type of changes in the vibrations that can be seen in a speaker cone when it plays sounds of different volumes and sounds of different frequencies. A speaker cone is deformed when electrical energy is supplied to it. 	**Conduct an investigation** to produce data to serve as the basis for evidence to answer scientific question *raised in our last lesson about the predicted* patterns *we expect to find between the* amplitude and frequency of vibrations *of the stereo speaker and the type of* sounds it produced *in terms of* volume and pitch.	We looked back at the phenomenon of the speaker and the truck, and reviewed our predictions about what we should see the speaker doing when it produces sounds of different loudness or different pitches. But we wanted to confirm our predictions too, so we decided one easy way to do that would be to take apart or look inside a speaker to see if it was doing this as it produced different sounds. But when asked if we all really have seen or felt a speaker do this, some of us claimed that we haven't seen a speaker do this and wanted to confirm some our predictions. So we decided to look closely at a speaker as it makes sounds. We took the grill off a physical speaker and noticed patterns in its structure (a cone) and in the patterns in the motion of the cone of the speaker as it produced sounds. ● The amplitude of vibration was greater for louder sounds. ● The speed at which the speaker moved back and forth (if frequency of vibration) changed for the different pitch notes produced. We made a prediction; that the speaker is being forced to vibrate back and forth in lots of different ways because of something related to the electrical energy it is provided when hooked up to an electronic device. We conducted an investigation to explore this with a battery, wires, and a speaker and noticed some patterns: ● Hooking a source of electrical energy (a battery) up to the speaker makes the cone deform. ● We could change how fast it deformed back and forth, by changing how frequently we connected/disconnected the battery. We argued from evidence that: ● Applying electrical energy to a speaker makes it deform. The more energy we apply to the speaker, the further it would deform; this would affect the amplitude it can be forced to vibrate, and how loud the sound is it produces. ● Changing the rate that we provide and remove electrical energy to the speaker affects how frequently it moves back and forth. This would affect the pitch of the sound it produces.. This raised some new questions, which we investigated further in a Home-Learning: *What is inside the iPod/computer/phone that knows how to make the music? How do these electronic devices record and playback things like sounds anyway?* **Next steps: We argued that if we could take apart a speaker and see how it works, and/or rebuilt it, that this too might help us better understand how electrical energy is used to make the speaker move.**

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This Lesson....What we are doing now: You will help students examine the components of a speaker by analyzing two videos of disassembling a speaker as a whole class. Students will then assemble and test this system of three parts, and they will find that it plays music from various electronic music players.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L22: What else is inside a speaker that makes it move? (Optional Embedded Assessment #5) 1 period: 40 min *Building toward* *NGSS PEs:* *1-PS4-1* *MS-PS4-3* *MS-PS3-5* *MS-PS4-1* *MS-PS2-3*	Two videos show the an electronic speaker being dissected. A homemade speaker built out of magnets, an insulated wire coil, and a cup/plate, plays music from an electronic music player when hooked up the ends of a striped aux. cord. 	**Design a solution:** Apply scientific ideas to design, construct, and test the design of different objects *(structures) to determine which produces better sound quality (function) when hooked up to a coil of wire and a magnet when plugged into an electronic music device to play back music stored on the digital device.*	Taking the grill off a speaker and seeing what was inside that appeared to vibrate when it produced sounds raised more questions. *How does this happen? How is the cord going from the iPod/computer/phone to the speaker getting the speaker to move?* We thought maybe there was something inside the speaker (perhaps electronics) that makes it vibrate; so we decided to inspect what is inside the speaker further. We watched two videos of people taking apart speakers. We noticed a pattern between the structures in the speakers: ● Each had a coil of wire, a magnet, and a surface that the coil or magnet was attached to (a cone, pad, or plate). We wondered *if putting these three structures together would make it function as the speaker does when we hook it to an electronic music device (tablet, phone, etc.)*. We were a bit skeptical that hooking these three things up would make a functioning speaker system for something like a smartphone, but we wanted to try. We conducted an investigation following a simple procedure and discovered some interesting patterns in designs that produced sound: ● Using hot glue to attach a wire coiled in many loops to an object and then connecting the wires on an aux cord to the ends of the wire coil, can turn that assembly into a speaker that plays music when we bring a magnet near the center of the coil of wires. ● Different objects can be made to vibrate and produce sound from a electronic music source. ● The material and shape of the object used as a cone/plate seemed to affect the quality of sound produced. We argued from evidence that: ● The interaction between magnets and variation in the amount of electrical energy provided to the coil of wire somehow is converted to motion, which produces vibrations which produces sound. ● Maybe similar structures are found in a microphone. **Next step: We want to figure out what is in a microphone, how it works, and how it compares to a speaker. We also want to know how the music player "knows" how to make the object that is vibrating move the way it needs to in order to produce a sound. We will investigate this a bit more through our home-learning readings.**

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This Lesson....What we are doing now: This lesson marked the end of Bend 4. You will help students compare how early recordings were made vs. how digital recordings are made today. Students will evaluate that advantages and disadvantages of analog vs. digital forms of audio information for recording, storage, copying, transmission, and playback.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figured Out (CCCs & DCIs), *New Questions* and **Next Steps**
L23: How were audio recordings made, copied, and played back long ago vs. now? 1 period: 40 min Recommended: an additional full period beyond this to look back on your earlier work and reflect on how much you've accomplished. S *Building toward* *NGSS PEs: 1-PS4-1 MS-PS4-2. MS-PS4-3.*	Historical descriptions and video clips show Edison wax cylinders being etched by an early recording device, and the cylinder then being used to play back the song that was recorded. A video clip shows how vinyl records are copied today.	**Obtain, Evaluate, and Communicate information:** Critically read scientific texts (historical descriptions) adapted for classroom use *and videos* to determine the *structures and their related functions in the earliest devices for making analog recordings of sound* (designed world).	In our home-learning, we figured out that cochlear implants have structures that function similar to damaged structures in the cochlea, microphones have similar structures to a speaker, but work in reverse. We revisited the record from the first lessons and brainstormed: How did they record music before there were microphones and digital recording devices? How did they make plastic records before computers were available? And did people figure out any other ways to make audio recordings before that? We then looked at videos and historical descriptions of the first invention for recording sounds—the Edison cylinder, as well as the material breakthrough that allowed for the replacement of vinyl for wax/foil. We developed and revised a model of how we think it records and plays back sounds using a cone, needle, and wax/foil cylinder. We compared this form of information (analog) recording, storage, and playback and argued that: ● It is harder to record analog information on a record than it is in a digital file using an electronic device. ● It is harder to copy analog information on a record than it is from a digital file using an electronic device. ● It is harder to send analog information to faraway places than it is in a digital file using an electronic device. ● It is easier to damage a record of analog information (a record) than it is in a digital file using an electronic device; but digital files can accidentally be deleted and records can not. Optional: After this lesson we wrapped up our storyline by: ● Sharing out the % of questions you our class felts we figured out an answer to. ● Looking back on our earlier work and reflect on how much we've grown. ● Celebrating what we accomplished working together. ● Reflecting on what was hard, what was rewarding, and what goals our learning community has for the next storyline we embark on!

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