Hearing and Sound

INTRODUCTION

In this two-part lesson, students begin to understand sound wavelengths and their behavior through observing a unique phenomenon (using sound to extinguish a fire). Even though wavelengths are invisible to us, they still exist and have different properties that we can learn about. Students then build on previous learning and understanding about sound (in particular, concepts from 1-PS4-1 and 1-PS4-4, in which students learned that vibrating materials make sound and that sound can make materials vibrate; and creating a device using sound to communicate over a distance). They are asked to share their pre-existing knowledge and ideas about how humans hear sound and how sound is produced, generating a common mind map that is revisited and added to over the remainder of the lesson as more is learned. To wrap up Part 1, students play a digital interactive called **How We Hear**, responding to guiding questions and learning through experimentation in a digital environment. This game explores sound from multiple angles, including how different animal species hear sound and anatomical structures involved in interpreting sound. The game also supports students in understanding that:

- Waves can cause objects to move.
- Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks).

In the second part of the lesson, students participate in a creative, hands-on STEAM (Science, Technology, Engineering, Arts, and Math) project. They are asked to create a new musical instrument, or a device that creates sound in a new and interesting way. Depending on the students' needs and/or the teacher, this project can be presented as an open-ended challenge, or creative prompts (provided in this lesson) can be given to students as artistic inspiration for their instrument. The design project also asks students to provide peer feedback and for students to modify their instrument prototypes based on experimentation and feedback, making improvements through an iterative process. For more information on the intersection of Science, Technology, Engineering, Arts, and Math, refer to **Appendix A: STEAM Projects**.

STANDARDS

Throughout this lesson, when Next Generation Science Standards (NGSS) are explicitly incorporated into activities, they will be color coded as appropriate: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models	4-PS4-1	Patterns
Using Mathematics and Computational Thinking		Cause and Effect
Constructing Explanations and Designing Solutions		Structure and Function
Obtaining, Evaluating, and Communicating Information		

KEYWORDS

Hearing, sound, audio, music, design, pitch, amplitude, wavelength, senses, volume, vibration, STEAM.

TIME

2-3 class periods

MATERIALS

- Digital access to **How We Hear**
- Variety of construction materials for building musical instrument prototypes - students can provide, or use miscellaneous classroom materials - examples include:
    - Scissors, tape, glue
    - Cardboard
    - Construction paper
    - Popsicle sticks
    - Straws
    - Plasticine
    - Elastic bands
    - Plastic bottles, tubes, recycling bin materials
- **Appendix B: Hearing and Sound Student Workbook**
- **Appendix C: How We Hear Project Rubric**

HOW TO DIFFERENTIATE AND ENRICH LEARNING

Knowledge is accessed and built by:

- Watching and listening to videos and presentations
- Discussing and interviewing
- Reading text, articles, and research papers
- Viewing and interpreting images, photos and graphs
- Note taking by writing or voice recording (audio workbook)
- Mind-mapping
- Collecting and tracking real-world data

Knowledge is applied/contextualized, practiced, and understood by:

- Sharing personal stories
- Game play with flexibility for reinforcing/repeat
- Choosing personally relevant research topic or project
- Testing ideas through building, experimenting, and prototyping
- Answering formative (check-in) assessment questions
- Drawing and creating storyboards and diagrams
- Evaluating and incorporating feedback

Knowledge and understanding are demonstrated by:

- Thoughtful reflections and accurate answers in writing or otherwise (journal, test etc)
- Final product uses choice of multi-media (video, website, poster, podcast)
- Creating a product with real-world relevance/applicability
- Creating a product for users/audiences beyond the classroom
- Final product meeting rubric indicators – with student choice for what should be assessed
- Formal oral presentations; participation in campaigns and model displays
- Building model representations for visualizing things that are too small to see
- Collaborating and providing useful/correct feedback to others

Day 1: Introduction to Sound

On Day 1, students will review their existing knowledge about how sound and hearing work (first introduced in 1-PS4-1 and 1-PS4-4) before expanding into the outcomes of 4-PS4-1 that address sound wavelengths and wavelength behavior. The idea of wavelengths as invisible and yet able to create effects in the environment around them is a concept that can be difficult for students to understand, so students are first engaged in this idea through experiencing a unique phenomenon - using sound waves to extinguish a fire. Seeing this cause-and-effect relationship demonstrates to students that waves, while invisible, exist and have an impact. They can then translate this knowledge into other more subtle scenarios in their real world, such as the impact that sound waves would have on anatomical structures within the ear.

To bring together the collective knowledge of the class, a conceptual mind map focused on the word "sound" is created. This mind map is intended to be a living document and revisited throughout the lesson to reflect new knowledge acquired through activities and correct any misconceptions or misunderstandings that students may have had at the outset or as they build on their understanding of hearing and sound.

Day 1 concludes with game play; students access the digital interactive **How We Hear** on Wonderville.org. This interactive explores a "sound laboratory" through the perspective of a cat named Proton. Students navigate Proton to different focus areas throughout the lab, and at each station they learn about a different aspect of hearing and sound. By the completion of this digital activity, students should have deepened their understanding of sound wavelengths (including differences in amplitude and frequency); vibrations and the impact of sound wavelengths on other media; anatomy of both a human and a cat ear to explain how structures are related to function in these respective species; and comparing hearing capabilities across multiple animal species. To assess for understanding, students complete the accompanying assessment found in **Appendix B: How We Hear Student Workbook.** It is recommended that teachers review responses to this formative assessment between Day 1 and Day 2, and begin Day 2 with a review of concepts from the game and address misunderstandings apparent in student responses in the assessment. Before beginning project work, it is important that the class understands these game concepts; the assessment can be re-taken and the game played as many times as needed before moving forward.

Components for Day 1:

- **Video: Pump Up the Bass to Douse a Blaze: Mason Students' Invention Fights Fires**
- **How We Hear** (digital game)
- **Appendix B: How We Hear Student Workbook**
- **Appendix D: How We Hear Assessment Answer Key**

Day 1: Outline

1. Start the class by watching this phenomenon-based video of sound waves being used to extinguish a fire: **Pump Up the Bass to Douse a Blaze: Mason Students' Invention Fights Fires**.

   Note: Background information for teachers about this phenomenon is available by visiting this article: **https://techxplore.com/news/2015-03-students.html**

Day 1: Outline Continued...

2. Ask the students to respond to the following questions (this can be conducted as a whole class, or students could first share their ideas with an elbow partner before coming together as a larger group):
    A. What is happening in this video?
    B. How does this work?
3. Have students complete the student reading and respond to the discussion questions in their **Appendix B: How We Hear Student Workbook.** Then, return to the video and re-assess the class: how have their answers to the questions "What is happening in this video? and, How does this work?" Changed now that they have read the student reading?
4. To connect these ideas around wavelength to the rest of students' knowledge of hearing and sound, a class-wide mind map (**Appendix E: Sound mindmap**) will be created. Write the word "sound" in the middle of a whiteboard, with the sub-questions "How is sound created?" and "How do we hear?" alongside it, to begin a collaborative mind map. Begin to collect students' ideas and knowledge about sound (note that this will be continually revisited during the lesson). An example of categories or themes to begin a mind map is shown below.

Connect students' personal experiences, culture and family experiences to this topic by asking students to share stories about the sounds, instruments and music that are meaningful to them and/or their culture.

5. Have students play the Wonderville game, **How We Hear.** As they work through the activities embedded in the game, challenge them to work as individuals or in pairs to complete the assessment found in **Appendix B: How We Hear Student Workbook.**
6. Have students share responses and expand upon the sound mind map to reflect new knowledge. Either at the end of Day 1 or at the beginning of Day 2, as a class review the concepts learned during game play as well as student responses on the assessment found in **Appendix B: How We Hear Student Workbook**. This assessment is intended as a checkpoint for student understanding and is important as a foundation for project work. Class discussion to correct any potential misconceptions, repeated game play, and revisiting this assessment are encouraged as ways to solidify student understanding and ensure appropriate terms, concepts, and applications are brought forward into the project.

Days 2-3: Instrument Design Challenge

Spanning approximately two class periods (time will vary depending on the group), the instrument design project is intended to apply the concepts of sound, wavelength, and how we hear sound to a real-life device that students regularly encounter: a musical instrument.

Taking an interdisciplinary approach to the challenge (see **Appendix A: STEAM Projects)**, students will be asked not just to demonstrate their scientific understanding of hearing and sound, but to be creative and artistic in designing something unique that can make music. They start first by drawing a model of their instrument, using both illustrations and words to show their design concept as well as how sound waves will be produced. They then share these models with their peers, using feedback provided to make changes and improvements to their instrument design. Constructing an instrument prototype using a variety of household and classroom materials will permit students to visualize their instrument idea in 3D.

Days 2-3: Instrument Design Challenge Continued...

Once the instruments are complete, along with responses to the guiding questions found in the student workbook, students share their final designs with their peers and use appropriate scientific terminology (wavelength, vibrations, pitch, amplitude, frequency) to describe the sounds they create. There are a number of options for how teachers and students can further synthesize this content. These suggestions include:

- Having individuals, small groups, or the whole class compose a song
- Creating bands to perform to other classes using the instrument prototypes
- Making a music video to share online

To make even more connections to the Mathematics component of STEAM, in song composition teachers can emphasize time signature (2/4, 3/4, 4/4, etc.) and explore how bars or measures are used to organize music in a predictable pattern for musicians.

Note: **Appendix B: How We Hear Student Workbook** is intended to be submitted along with the three-dimensional instrument for evaluation against **Appendix C: How We Hear Project Rubric** Regardless of whether students construct their instrument as individuals or in groups, they should be assessed as individuals. In order to acknowledge diverse learning styles and/or support students who may need other accommodations, students should also be given the choice to respond to the questions in the workbook in different formats (e.g., video, podcast, other multimedia). Regardless of the medium chosen to present responses, it is important that students understand that their submission must demonstrate understanding and answer the questions as comprehensively as possible.

Components for Days 2-3:

- **Appendix A: STEAM Projects**
- **Appendix B: How We Hear Student Workbook**
- **Appendix C: How We Hear Project Rubric**
- **Optional: Instrument Design Challenge Prompts**

OUTLINE

1. Present students with the design challenge:

   Create a new musical instrument.

   This should be connected back to the content covered on Day 1 - reminding students that not only will they need to be artistic and creative in their instrument, but that they will also need to present their instrument to the class using appropriate scientific terminology (wavelength, vibrations, pitch, amplitude, frequency).

   Review the guidelines or expectations for the project - these can be used as below, or created as a class:

- The goal is to create a new musical instrument that makes sound in any way.
- All materials used for the construction of the instrument must be pre-approved by the teacher (and/or provided directly by the teacher).
- Students can complete the task as individuals or in groups of 2-4 students (note: assessment will be by individual, regardless of choice for construction of the instrument).
- All designs must be unique and original. The instrument can take inspiration from an existing musical instrument design, but the goal is to be creative in the method that your instrument makes sound.

Days 2-3: Outline Continued...

Note: Alternatively, you may wish to provide students with more structure for this project as an alternative to this flexible, open-ended approach. The following prompts can be used to guide students in their instrument creation. These prompts can be cut out and one provided to each student (or student group) to get them started:

CREATE AN INSTRUMENT THAT IS A MASHUP (COMBINATION) OF TWO OR MORE REAL INSTRUMENTS.
MAKE AN INSTRUMENT THAT YOU HAVE TO TWIST TO CREATE A SOUND.
CREATE AN INSTRUMENT THAT IS INSPIRED BY A DR. SEUSS STORY.
BUILD AN INSTRUMENT THAT MOVES A PIECE OF PAPER WHEN IT CREATES MUSIC.
CREATE AN INSTRUMENT THAT WORKS UNDERWATER.
MAKE AN INSTRUMENT THAT USES ELASTICS IN THE DESIGN, BUT YOU CAN NOT TOUCH THEM DIRECTLY.
CREATE AN INSTRUMENT THAT YOU HAVE TO STAND INSIDE OF TO CREATE MUSIC.
CONSTRUCT AN INSTRUMENT USING ONLY PLASTICINE.
MAKE AN INSTRUMENT THAT CAN PLAY AT LEAST FIVE DIFFERENT NOTES (PITCHES).
CREATE AN INSTRUMENT THAT YOU USE YOUR FEET TO PLAY.

Days 2-3: Outline Continued...

2. **Model:** Students should draw a labeled diagram of their instrument concept. This should illustrate their design and identify, in words, what features will be present on their instrument in order to create sound. Their diagram should also model the vibrations or sound waves created when music is produced - for example, illustrating how air particles around the instrument would move when sound is made (similar to the bell example in the How We Hear game).
3. **Feedback & Revision:** Have students share their model with at least one other group (or the entire class), giving peer feedback for amendments and improvements to all designs. Following this feedback, students should return to their models to make changes.
4. **Prototype**: Using approved materials, allow at least one class period for instrument construction. If time permits, this can be extended into multiple class periods, giving students the opportunity to build an initial prototype, test how well it works, share with other students and collect feedback for revisions. Prototypes can be refined and amended based on peer feedback and testing.
5. When final instrument prototypes are created, have students present their ideas to the class. This presentation will require that students:
   A. Demonstrate/play their instrument
   B. Use appropriate terminology to explain how sound is being created and describe the qualities of the sound waves produced
6. As a final activity to further reinforce understanding of sound waves, the class can attempt to create a continuous line of instruments where the lowest pitch is on the far left and the pitch of sound created increases moving to the right of the line (if a particular instrument can produce multiple notes/pitches, they should select just one to play for this exercise). As individuals or as a class, draw what the lowest pitch wavelengths would look like as opposed to what higher-pitched wavelengths would look like.
7. For final assessment, have students submit their final instrument prototype, along with their Student Workbooks, for evaluation against the project rubric.
8. **Additional Extensions:** Further creative activities, such as composing a song, creating bands or a collaborative "orchestra" to perform in the school, or making a music video to share online are encouraged as ways to further explore sound and music. To make even more connections to the Mathematics component of STEAM, in song composition teachers can emphasize time signature (2/4, 3/4, 4/4, etc.) and explore how bars or measures are used to organize music in a predictable pattern for musicians.

Connecting Music and STEM

For more connections between music and STEM, check out **Orchestra Conductor** on Wonderville.org. To introduce students to how to read music, including recognizing time signature, beats and measures, watch How to read music and have students practice identifying the patterns (time signatures) in popular songs. Students should be able to distinguish between 3/4 time (three beats per measure) and 4/4 time (four beats per measure) by clapping out the beats. The strongest beat (the first beat of the measure) is called the "downbeat" and is usually the easiest to recognize.

Appendix A: STEAM Projects

STEAM Defined

STEM – the delivery and integration of science, technology, engineering and mathematics - is a familiar concept. STEAM incorporates the arts and design, recognizing that students' ability to be creative and use critical thinking is enhanced when also exposed to the arts.

As with STEM, the five tenets of STEAM should be viewed as interdisciplinary rather than as standalone subjects, for it is the integration that deepens student learning.

Interdisciplinary Learning: a grade 8 case study of STEAM in action

Two grade 8 teachers in Calgary, Canada used an interdisciplinary, STEAM-based approach to deliver four subject areas simultaneously using game-based design and game-based learning.

Over a six-week period, students were challenged to create games based in the Renaissance period (tackling the Social Studies curriculum), involving mechanical systems (Science and Engineering) and number sense operations (Math), all presented in a creative and compelling fashion (English Language Arts).

Students began with an exploration of games to understand how games deliver educational value in an alternative medium. They then developed their own interdisciplinary games, combining content from all four core subject areas. The participating teachers reported that the project was empowering and engaging for diverse students, and that it taught valuable skills; students said that they learned a lot more than the standard curriculum by needing to do extra research for their games – and that rich understanding was delivered through the process of creating their games.

Benefits

A STEAM-based approach to teaching addresses diversity in student learning styles, particularly for students that struggle with more traditional, lecture-style structured activities. Things like collaborative group work, student independence, and a culture of integrated learning that mimics the real world are all key aspects of this approach to classroom instruction.

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

HOW WE HEAR ASSESSMENT

Questions

1. Sound starts with ________.

   Explain your answer: ____

   ____

2. Could you hear an asteroid flying by in space? Why/why not?

   Explain your answer: ____

   ____

3. True/False: A lion roaring would create bigger vibrations than a cat purring.

   Explain your answer: ____

   ____

4. At the beakers, you learned that when there was more water in the beaker, there was more material to vibrate. That slowed down the vibrations, and a sound with a lower pitch was made. Based on that knowledge - which pipes on the instrument pictured below will make the lower pitched sound? The short pipes, or the long pipes - and why?

   ____

   ____

   ____

5. What are three differences between Proton the cat's ear and your human ear?

   ____

   ____

6. Hey! There was a sound made that was only 1 Hz. Who heard it?

   A. Bat
   B. Cat
   C. Human
   D. Elephant
   E. Mouse

   Explain your answer: ____

   ____

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NAME: ________________ **CLASS**: ________________ **DATE**: ________________

HOW WE HEAR ASSESSMENT CONTINUED

Questions

7. True/False: Just like in space, you can't hear under water.

   Explain your answer: ____

   ____

8. What is the first part of the human ear that vibrates like a musical instrument when sound waves hit it?
   A. Anvil
   B. Cochlea
   C. Eardrum
   D. Ear canal

   Explain your answer: ____

   ____

9. When you are silent, your vocal cords remain _____.

   Explain your answer: ____

   ____

10. Did you listen to the radio? Look at the wavelength below - is it from the drum beat, the opera singer, or talk radio? How do you know?

    ____

    ____

    ____

    ____

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

STUDENT READING

Snuffing Out Fires with Nothing But Sound

If you've ever seen a fire put out with a fire extinguisher – you'll know that there's quite a bit to clean up after. But what if you could put out a fire with no chemicals at all?

Two engineering students have done just that, building a prototype fire extinguisher that uses nothing but sound waves.

The science behind it is simple - mechanical pressure waves cause vibrations when they travel, meaning that sound waves have the potential to affect the burning material of a fire and the oxygen that surrounds it. If the right frequency and concentration is discovered, the sound waves could potentially starve out the oxygen and snuff the fire out.

The sound wave extinguisher narrows and focuses the sound waves, and after some experimentation, the researchers found that low frequency, bass waves worked the best. I guess it really is "all about the bass". You can check out the extinguisher in action **here**.

What is happening in the video?

____

____

____

How does this work?

____

____

____

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NAME: ________________ **CLASS**: ________________ **DATE**: ________________

PROJECT INSTRUCTIONS

Your task? Create a new musical instrument.

All over the world, people listen to music and create music with a wide variety of instruments. Every single country on Earth has music!

Imagine that you're in charge of creating a new type of sound for kids today (every generation has cool new music!). You need to create a new, never seen before, musical instrument. As a class, you'll go over the "rules," but here are some guidelines for your project:

- The goal is to create a new musical instrument that makes sound in any way.
- All materials used for the construction of the instrument must be pre-approved by the teacher (and/or provided directly by the teacher).
- You can complete the task as individuals or in groups of 2-4 students (note: assessment will be by individual, regardless of choice for construction of the instrument).
- All designs must be unique and original. The instrument can take inspiration from an existing musical instrument design, but the goal is to be creative in the method that your instrument makes sound.

Do you think you've got what it takes to make a popular new musical instrument? Maybe you can start a band with it, or make a music video - who knows where this will take you. Good luck!

Notes to Students

If you want to present your responses to the questions in this Student Workbook in an alternate format (e.g., podcast, video, other multimedia), this may be an option. Check with your teacher and get approval if you want to submit your Student Workbook in one of these other ways.

NAME: _______________ **CLASS**: _______________ **DATE**: _______________

YOUR INSTRUMENT MODEL

Use the space below to draw a model of your instrument idea.

- Use pictures to illustrate the structure of your instrument.
- Use words to show where/how sound is created by your instrument.
- Incorporate your understanding of wavelength, vibrations, pitch, amplitude, frequency into your model - you'll need to know how these apply to the music you create.

NAME: ________________ **CLASS**: ________________ **DATE**: ________________

What changes did you make to your model after getting feedback, and why did you make these changes?

____

____

____

Will your instrument be able to make more than one type of sound (wavelength)? If not, why not? If yes, explain how the sounds will be different (think about pitch and frequency!).

____

____

____

Use the space below to explain your instrument and how it works. This will be useful for your presentation. Think about:

- What was the inspiration (idea, concept) for your instrument?
- Are there any real instruments it is similar to?
- How does it produce sound?
- How can the words wavelength, vibrations, pitch, amplitude, and frequency be used in your explanation of how your instrument works?

____

____

____

____

____

____

____

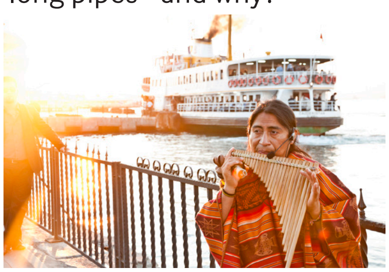
Appendix C: How We Hear Project Rubric

How to use this rubric:

- Provide this rubric in advance of starting the project - make sure that students understand evaluation - or, if desired, the indicators can be created collaboratively with students for greater ownership over what they are trying to achieve.
- This rubric can be used both for self-reflection and for teacher evaluation.
- Students can choose which four of the six categories they wish to be evaluated on, for a total of 100%. Teacher comments and feedback is encouraged for all categories, regardless of which scoring categories are selected.

OUTCOMES	Indicators (can be demonstrated in different ways)	Comments and Feedback	Score
Research and self-directed learning	• Documents information and ideas effectively • Provides clear and complete answers • Shows correct understanding of concepts • Demonstrates understanding of the relationship between function and design		25%
Design and Model	• Shows correct application of ideas and learnings • Illustration clearly shows instrument structure • Words explain both the parts and functionality • Includes creative/original elements		25%
Prototyping	• Uses materials, equipment, class space and time adequately and responsibly during the building and testing process • Builds prototype that closely follows the model • Prototype effectively creates sound		25%
Revisions	• Troubleshoots effectively and revises model to address feedback • Justifies and explains revisions • Changes the prototype as per revised design		25%
Collaboration	• Provides useful feedback on other designs • Considers and incorporates feedback and suggestions from others • Makes thoughtful contributions to class discussions and debriefs • Has respectful and productive interactions with others		25%
Communication and Presentation	• Communicates in ways that are logical and effective; to others, can back up ideas and have meaningful and constructive dialogue • Shares and justifies ideas and information clearly and thoroughly • Presents in a confident and engaging fashion showing understanding and competence		25%

Appendix D: How We Hear Assessment Answer Key

Questions	Suggested Student Responses
1. Sound starts with ________.	Vibrations. From the Blackboard: Sound starts with something moving or vibrating (in this case, the bell). The vibrating bell moves particles in the air that bump into each other, one particle after the other.
2. Could you hear an asteroid flying by in space? Why/why not?	No, because there is no sound in outer space. From the Corkboard: Sound waves need a medium to travel through. In outer space, there is no air for the sound to travel through.
3. True/False: A lion roaring would create bigger vibrations than a cat purring.	True. From the Cymbals: When the vibration is larger, so is the sound. For example, when you hit cymbals together to create a loud sound, the vibration is large. When the cymbals were hit together hard (like a lion roaring), they vibrated more and the sound was greater.
4. At the beakers, you learned that when there was more water in the beaker, there was more material to vibrate. That slowed down the vibrations, and a sound with a lower pitch was made. Based on that knowledge - which pipes on the instrument pictured below will make the lower pitched sound? The short pipes, or the long pipes - and why? 	From the Beakers: The long pipes will make the lower pitched sound. The longer wavelength through the longer pipe makes a lower pitch.
5. What are three differences between Proton the cat's ear and your human ear?	From the X-ray viewer: Answers may include: Cats have 20+ muscles to use their external ears. Human have about six. Cats external ears are shaped like a cone, and humans are not - we funnel sound differently. Humans can't move our ears in different directions. Cats can hear sounds as high as 65 kHz; humans can't hear that high.

6. Hey! There was a sound made that was only 1 Hz. Who heard it?
   A. Bat
   B. Cat
   C. Human
   D. Elephant
   E. Mouse

D (elephant). From the Whiteboard: The ranges of sound that animals can hear are all different. Elephants can hear 1-20,000 Hz. In contrast, bats (2,000-110,000 Hz), cats (45-65,000 Hz), humans (20-20,000 Hz) and mice (1,000-100,000) would not be able to hear a 1 Hz sound.

7. True/False: Just like in space, you can't hear under water.

False. From the Fish Bowl: You can hear sounds in water. Sound waves travel through particles in the water in the same way they travel through air. If you rang a bell under water, the vibration from the bell would cause particles in the water to move. The sound wave from the bell would travel from one particle in the water to another.

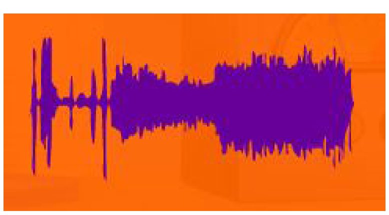
8. What is the first part of the human ear that vibrates like a musical instrument when sound waves hit it?
   A. Anvil
   B. Cochlea
   C. Eardrum
   D. Ear canal

C (eardrum). From X-ray: The eardrum vibrates when sound waves hit it. It then makes the three bones in the middle ear move, one after the other.

9. When you are silent, your vocal cords remain _____.

Open. From the X-ray: When you are silent, your vocal cords remain open. The air you breathe moves through this opening. But when you speak, the air you exhale from your lungs is forced through the closed vocal cords, causing them to vibrate. This vibration is how sound is made with your vocal cords.

10. Did you listen to the radio? Look at the wavelength below - is it from the drum beat, the opera singer, or talk radio? How do you know?



It is from the opera singer. From the Radio: The opera singer has a high pitch sound. The peaks in the sound wave are close together. Compare this to the drum beat, where the peaks are much farther apart and are not as high (lower amplitude).

Appendix E: Sound mindmap