Science News
EDUCATOR GUIDE

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January 18, 2020
Saving Notre Dame's Sound

SOCIETY FOR SCIENCE & THE PUBLIC

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Saving Notre Dame's Sound

About this Guide

This Guide, based on the *Science News* article "Saving Notre Dame's sound," asks students to explore how scientists resurrect the acoustics of historic places, consider factors that affect how sound behaves to design a room with specific sound requirements, and measure and compare how sound changes in different environments.

This Guide includes:

Article-based Comprehension Q&A — These questions, based on the *Science News* article "Saving Notre Dame's sound," Readability: 10.7, asks students to analyze how scientists plan to resurrect the acoustics of a historic place. Related standards include NGSS-DCI: HS-ETS1; HS-PS4; HS-PS3; HS-PS2.

> **Student Comprehension Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Cross-curricular Discussion Q&A — Drawing on their experiences with how sound behaves in different spaces, students will explore the engineering process by designing and sketching a room to meet specific sound requirements. Related standards include NGSS-DCI: HS-ETS1; HS-PS4; HS-PS3; HS-PS2.

> **Student Discussion Worksheet —** These questions are formatted so it's easy to print them out as a worksheet.

Activity: A World of Acoustics

> **Summary:** Students will use decibel meters to understand how the volume of a sound changes as it travels away from a source. Concepts covered include sound waves, the inverse square law, absorption and reflection. The activity also asks students to consider how the characteristics of a space affect the sound. Related standards include NGSS-DCI: HS-PS4; HS-PS3; HS-ETS1.
>
> **Approximate class time:** 1 class period for data collection and mapping, plus work at home to complete the activity questions.

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Article-based Comprehension, Q&A

Directions for teachers: After your students read "Saving Notre Dame's sound," ask them to answer the following questions. Questions are organized by subsection with general questions at the top — in case you want to divvy up the reading among students. Note: You may want to show students acoustician Brian Katz's virtual reality simulation of a concert in Notre Dame that re-creates acoustics from various locations. If viewing on a desktop, click and drag on the video to rotate the perspective. For mobile viewing, direct your students to move their phones to rotate the perspective.

Introduction

1. What is Notre Dame and where is it located? What event damaged Notre Dame in 2019?

Notre Dame is a historic cathedral in Paris, France. A fire in April 2019 destroyed the cathedral's roof and spire and damaged other parts of the church.

2. What role do acoustics researcher have in restoring Notre Dame? What field has their work put in the spotlight?

Acoustics researchers are trying to reconstruct how Notre Dame sounded before the fire, which could be used to predict how renovations may change the cathedral's sound. The research has brought attention to the field of heritage acoustics — or the study of sound in historical buildings.

Aural history

3. What is a sound wave? What is the difference between an echo and reverberation?

A sound wave is how a sound moves through air. Sound waves are made of vibrating air molecules that cause variations in pressure. An echo is a delayed repetition of an original sound, made by sound waves bouncing off a single surface. Reverberations are created when sound waves bounce off many surfaces and can't be distinguished individually. We perceive the sound as fading over time.

4. What is reverberation time? Name two factors that can affect a room's reverberation time.

Reverberation time is the number of seconds it takes for a sound to fade by 60 decibels. The materials in a room and the size of the room can influence reverberation time. Rooms with marble and limestone, which tend to reflect sound waves, have longer reverberation times. It takes sound waves longer to travel between surfaces in larger rooms, which can increase reverberation time.

Sound of silence

5. What did researcher Brian Katz record in 2013 and why is this recording considered special? Describe one acoustic property that Katz measured. Why is this measurement important?

Katz took detailed measurements of Notre Dame's acoustics. The recording is special because it is the only recording of its kind that exists. Katz measured the cathedral's room impulse response, or how the loudness of a sound varies after it is initially made. Researchers can use the room impulse response to figure out reverberation time and other acoustic properties that affect how listeners perceive sound.

6. What path did Katz take to become an acoustician?

It's interesting that Katz researches the physics of sound because he doesn't play any instruments and isn't a conventional physicist. He studied physics in college at Brandeis University in Massachusetts, but unlike his peers who were interested in the physics of the universe and cosmos, Katz was more intrigued by physics on the human scale. He eventually found his way to studying acoustics, thanks in part to setting up sound systems for events at school.

Music from ruins

7. What other buildings' acoustics have been re-created? How do those re-creations compare with Katz's work on Notre Dame?

Researchers have reconstructed the acoustics of a ruined English abbey and a 16th century Italian church. The English abbey reconstruction required researchers to make a lot of assumptions because only a few walls of the abbey and its arches remained. The researchers couldn't make detailed measurements like those at the Italian church or at Notre Dame.

8. What does the author compare to acoustic time machines? Why is the simile appropriate?

The techniques that researchers use to measure buildings' acoustic properties are like time machines because they can transport listeners to an earlier era by re-creating how buildings sounded in the past.

The measure of a cathedral & Tuning up

9. What was Notre Dame's average reverberation time in 2013? What characteristic of the sound affects reverberation time?

Notre Dame Cathedral has an average reverberation time of about six seconds. The reverberation time varies depending on the pitch, or how low or high a sound is.

10. How might Katz's simulation of Notre Dame aid rebuilding efforts?

The simulation re-creates the acoustics of the cathedral and so he can use it to test how various changes to the structure or materials used could affect the real cathedral's sound.

Crafting a soundscape

11. Who is Mylène Paroden? How does her work complement Katz's work?

Mylène Paroden is a soundscape archaeologist who reproduces ambient sounds of the past, including sounds that would have been heard on battlefields and on the streets of Paris outside Notre Dame. When combined with Katz's acoustic model, the reproduced sounds can reveal what a person might hear within Notre Dame at different periods in history.

12. What does acoustician Damian Murphy mean when he says that no historic building is ever completely static? How is this relevant to Notre Dame's rebuilding?

Murphy means that as time goes on, buildings are constantly changing. There is no single Notre Dame; it has changed a lot. Rebuilders will decide what the next Notre Dame looks and sounds like.

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Student Comprehension Worksheet

Directions: Read "Saving Notre Dame's sound" and answer the following questions.

Introduction

1. What is Notre Dame and where is it located? What event damaged Notre Dame in 2019?

2. What role do acoustics researcher have in restoring Notre Dame? What field has their work put in the spotlight?

Aural history

3. What is a sound wave? What is the difference between an echo and reverberation?

4. What is reverberation time? Name two factors that can affect a room's reverberation time.

Sound of silence

5. What did researcher Brian Katz record in 2013 and why is this recording considered special? Describe one acoustic property that Katz measured. Why is this measurement important?

6. What path did Katz take to become an acoustician?

Music from ruins

7. What other buildings' acoustics have been re-created? How do those re-creations compare with Katz's work on Notre Dame?

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The measure of a cathedral & Tuning up

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Cross-curricular Discussion, Q&A

Directions for teachers: After reading the article "Saving Notre Dame's sound," Readability: 10.7, students should work individually to design and sketch a room of their choice with a specific function and sound requirements. Students should then discuss their design with a partner and refine the design based on the feedback. Finally, students will think about how they might test their design before it would be built. Have students work through the prompts using the instructions below.

Directions for students: Think about a room or space that was designed to have specific sound requirements, like a concert hall, library or restaurant. Imagine you are tasked with designing a room with specific sound requirements. Use the prompts below to define your room's function, create and sketch a design based on your room's sound requirements, present your design to a partner and make any revisions based on your partner's feedback.

Define the room
Answer the following questions to define the room that you will design.

1. What will your room be used for?

2. What are the sound requirements of the room based on its function? (For example, do you want the room to increase or decrease the sound levels of voices? Of ambient noise? Do you want the sound to be uniform throughout the whole room or different in different places? Is the room a performance or social space?)

3. How many people will occupy the room?

4. What general size and shape do you want the room to be?

Apply your background knowledge
Think about a room in your school or elsewhere that is similar to the room you want to design. Using the prompts below, describe the characteristics of the room.

1. What is the general size and shape of the room? How high is the ceiling? How might the size and shape impact the acoustics? Would sound be different in different areas of the room?

2. What types of materials are typically found on the surfaces in the room? Are sound waves being absorbed or reflected by these materials? How do the materials affect the sound level in the room?

3. Is there generally furniture or other functional decorations in the room? If so, what are they made of and where are they located? How do these items affect the sound level in the area where they are located? What about in other areas?

4. How many people are generally occupying the room? Does the room's occupancy impact the room's acoustics? If so, how?

Design a solution

Using the sound properties of different types of rooms and keeping in mind the functional goal of your room, draw a rough sketch of your room. Make sure your diagram indicates general shape, scaled size and is labeled with structures, materials and/or furnishings that will influence the sound. Answer the following questions about your room and be prepared to discuss your room design with a classmate.

1. What is the size and shape of your room? Are there areas of the room where sound levels will differ greatly from others? Why or why not?

2. Why are you including certain materials in certain places? How do the materials you're using impact the sound waves in the room?

3. Is there furniture in the room? If so, where is it located and what is it made of?

4. Are there people in the room? If so, where will they be? How will their location and proximity to one another impact the sound that they hear?

Gather feedback and refine

Discuss your design with a classmate and get his or her feedback before answering the following questions.

1. How well does your design meet the sound requirements of your room? Be sure to think about the shape and scale of the room, as well as the materials you used.

2. Did your discussion with your classmate help you realize something new about your design? If so, how would you modify your design based on your discussion.

Testing

Consider how you might test your design by answering the following questions.

1. What questions would you want to test about your design?

2. What data would you want to collect to test those questions?

3. How might building and testing a prototype be helpful?

4. How important do you think sound requirements should be to how architects and interior designers do their work? Explain.

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Student Discussion Worksheet

Directions: Think about a room or space that was designed to have specific sound requirements, like a concert hall, library or restaurant. Imagine you are tasked with designing a room with specific sound requirements. Use the prompts below to define your room's function, create and sketch a design based on your room's sound requirements, present your design to a partner and make any revisions based on your partner's feedback.

Define the room

Answer the following questions to define the room that you will design.

1. What will your room be used for?

2. What are the sound requirements of the room based on its function? (For example, do you want the room to increase or decrease the sound levels of voices? Of ambient noise? Do you want the sound to be uniform throughout the whole room or different in different places? Is the room a performance or social space?)

3. How many people will occupy the room?

4. What general size and shape do you want the room to be?

Apply your background knowledge

Think about a room in your school or elsewhere that is similar to the room you want to design. Using the prompts below, describe the characteristics of the room.

1. What is the general size and shape of the room? How high is the ceiling? How might the size and shape impact the acoustics? Would sound be different in different areas of the room?

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3. Is there generally furniture or other functional decorations in the room? If so, what are they made of and where are they located? How do these items affect the sound level in the area where they are located? What about in other areas?

4. How many people are generally occupying the room? Does the room's occupancy impact the room's acoustics? If so, how?

Design a solution

Using the sound properties of different types of rooms and keeping in mind the functional goal of your room, draw a rough sketch of your room. Make sure your diagram indicates general shape, scaled size and is labeled with structures, materials and/or furnishings that will influence the sound. Answer the following questions about your room and be prepared to discuss your room design with a classmate.

1. What is the size and shape of your room? Are there areas of the room where sound levels will differ greatly from others? Why or why not?

2. Why are you including certain materials in certain places? How do the materials you're using impact the sound waves in the room?

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4. Are there people in the room? If so, where will they be? How will their location and proximity to one another impact the sound that they hear?

Gather feedback and refine
Discuss your design with a classmate and get his or her feedback before answering the following questions.

1. How well does your design meet the sound requirements of your room? Be sure to think about the shape and scale of the room, as well as the materials you used.

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Consider how you might test your design by answering the following questions.

1. What questions would you want to test about your design?

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4. How important do you think sound requirements should be to how architects and interior designers do their work? Explain.

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Activity Guide for Teachers: A World of Acoustics

Purpose: Students will use decibel meters to understand how sound changes as it travels away from a source, and how the environment shapes the sound. Concepts covered include sound waves, the inverse square law, absorption and reflection.

Procedural overview: After a teacher-led introduction, students will take decibel readings at different distances from a sound source in two different spaces. By pairing this data with their own maps of the spaces, students will determine how their results compare with what's predicted by the inverse square law. Writing down key details about each space will guide students as they consider how the environment can affect sound.

Approximate class time: 1 class period for data collection and mapping, plus work at home to complete the activity questions.

Supplies:

Per group
Decibel meter — this can be an application on a smart device (such as Decibel X for iPhone and Android, or NIOSH for iPhone), probes and/or microphones attached to meters
Tape measure
Paper, graph paper and pencil
Access to computers or calculators to determine expected decibel levels

Per class
A device to play a tone at the same volume — such as a smart device or laptop with a good speaker
Access to YouTube to play tones such as:

https://www.youtube.com/watch?v=rqRDla4zIZs
https://www.youtube.com/watch?v=xUZ4hUdZ2e8

Directions for teachers:
This activity begins with a teacher-led introduction. The teacher will walk through various concepts related to sound and how it travels — first, the inverse square law, and then the idea of reflection and absorption. Then comes the experiment, which will take place in two different spaces selected by the teacher. Students should use Part 1 of their activity guide to complete the experiment. Part 2 contains questions that students can answer in groups or at home.

The teacher will play a single tone at a single volume in each of the two spaces. Students who are particularly sensitive to sounds can be provided with earplugs or could be assigned to measure distances or record values after the sound has been stopped. Teachers should test the experimental setup in the two spaces selected to determine a single volume setting that is appropriate for the spaces, and to modify the predetermined distances as necessary.

Introduction
First, explain to students how sound spreads and dissipates.

Sound is created when vibrations from a source cause air molecules around the source to vibrate and collide with other molecules. For example, when a guitar string is plucked, the vibration of the string is transferred to the nearby air molecules, which collide with other molecules. When the energy of these collisions reaches a human ear, they cause the eardrum to vibrate, which triggers a host of other reactions that lead to a person hearing and interpreting sound. For more details on how humans perceive sound, check out this video, "Journey of sound to the brain," from the National Institutes of Health. As the sound travels, its energy is spread out in all directions covering a larger and larger area (some of the energy is also converted to heat energy due to the collisions of the molecules).

Since sound spreads in all directions from its source, the sound waves can be thought of as spreading in a spherical shape around the source. As the distance from the source (the radius of the sphere) increases, the surface area of the sphere increases as well. But the relationship is not linear: The surface area of a sphere is $4\pi r^2$, so the area increases exponentially as the distance from the source increases.

The relationship between the distance from the source (the radius, "r") and the decrease in sound intensity follows what's known as the inverse square law: The sound intensity is proportional to 1 over the square of the distance from the source (intensity $\propto 1/r^2$). Other physical measurements, such as the decrease in light intensity with increasing distance from a light source, also follow an inverse square law.

Intensity measurements are complicated by the fact that sound intensity is typically expressed using the decibel scale. The decibel scale expresses the intensity level relative to a fixed standard. The equation for converting sound intensity to decibels is $dB = 10 \log(I/10^{-12} W/m^2)$, where "dB" is decibels, "I" is the sound intensity in watts per square meter and $10^{-12} W/m^2$ is the reference intensity, representing the lowest intensity of sound a person with normal hearing can hear. The decibel scale is a logarithmic scale. An increase of 10 decibels means that the intensity has increased by a multiple of 10.

Next, explain how reflection and absorption affect sound waves.

The speed at which sound travels depends on how close the molecules are in the medium through which the sound is traveling (solid, liquid or gas). For example, sound travels faster through water than through air because the molecules in water are more closely packed (denser) than in air.

When sound travels from one medium to another, it can be reflected by the surface or absorbed to varying degrees. Hard, smooth surfaces like tile are more reflective than textured, soft surfaces like carpet. The combined effects of absorption and reflection determine how sound ricochets around a room. As reflected sound waves interfere with one another, they can become louder through constructive interference or softer through destructive interference. Auditoriums or concert halls are designed with these effects in mind. The size and shape of the space and the materials used help make it so everyone can hear what is happening on the stage clearly. Conversely, a library might have floors, walls and ceilings made of material that absorbs sound to ensure that sound does not disturb people who are trying to study.

Other objects in a room, such as furniture and people, will also absorb sound to varying degrees. If an absorbent material is located between the sound source and the listener, then the sound would be harder to hear.

The experiment
To explore the ideas of the inverse square law and absorption and reflection, this activity should be completed in two spaces of different sizes and with different acoustic properties: First, a large, open space (such as the gym, cafeteria or soccer field) to best illustrate the inverse square law, and then a smaller and more densely populated space (such as the classroom or library) that has more objects likely to absorb sounds. With a large, outdoor space, it will be necessary to define the boundaries of the space for your students (such as within the lines painted on the soccer field).

After measuring decibel levels at various distances from a source in two different spaces, students will compare the results from each space to the results expected from the inverse square law, and will compare each space to the other, to better understand how the acoustics of a space can change how simple sounds are heard.

Place students into small groups or pairs. Each group should have a measuring tape, pencil, paper and a decibel meter. Be sure to explain to the students that the value given by the decibel meter will likely fluctuate during use as small changes (such as background noise, the angles the meters are held, the movement of people in the space and so on) affect the intensity of the sound reaching the meters. Encourage students to try to obtain readings that are as stable as possible, or record the value that best approximates a stable reading.

In the first, open space, place the speaker of the device that will play the tone as close to the center of the space as possible. Have students measure the size of the space and make notes about the materials that cover the space and the number and types of objects (including people) in the space. Students should draw a map of the space, with objects, to scale.

Have the students with decibel readers stand around the speaker, creating a circle with a radius of 1 meter. Turn on the tone and have the students record the starting decibel reading. The students will then slowly and carefully walk directly away from the sound source in a straight line (like outward rays) and record the decibel reading for three additional distances: 2 meter, 4 meters and 8 meters. If students have to go around any objects, they should do their best to approximate the correct distances from the source.

Instruct students to record results at least twice at each distance and take an average of the data for that distance.

Next, have students repeat the procedure (observations, mapping and decibel readings) in the smaller space with more objects.

Students will answer the questions provided in groups or at home, according to your instructions.

Directions for students:
During this activity, you will be making observations about how the volume of a sound changes as it travels in two different spaces. Use Part 1 of this guide to complete the experiment. Part 2 contains questions that you should answer in groups or at home, depending on your teacher's instructions.

First, you will perform the experiment in an open space. You will need to measure the size of the space, as well as make notes about the materials that cover the space and the number and types of objects, including people, in the space. You will also want to make a map of the space for your reference later — don't forget to include the location of the speaker, as well as a key and scale bar.

Students holding the decibel readers will stand around a speaker as your teacher plays a sound. Create a circle with a radius of 1 meter. When the teacher turns the speaker on, record the decibel meter's reading and your decibel meter's initial distance from the speaker (1 meter).

The value given by your decibel meters will likely fluctuate during use as small changes (such as background noise, the angles the meters are held, the movement of people and so on) affect what intensity of sound reaches the meters. Try to obtain readings that are as stable as possible, or record the value that best approximates a stable reading.

Your team will then slowly and carefully walk the decibel meter directly away from the sound source in a straight line (like outward rays). You will record the decibels for three additional distances: 2 meters, 4 meters and 8 meters. If you have to go around any objects, do your best to approximate the correct distances from the source.

You will record results at least twice at each distance and average the data for that distance.

You will then repeat the procedure (observations, mapping and decibel readings) in the smaller space with more objects.

Part 1: Experiment

1. What is the first location in which your teacher has indicated the experiment will be done? Give a brief description by filling in the following details.

Location:
Length of space:
Width of space:
Height of space (estimated):
Materials in space:
Objects within space:
People within space:
Brief summary of space:

2. Draw a map of the space and its objects (be sure to include the location of the speaker, other objects, a key and a scale bar).

3. Create a table to record your data for the location. Include the distances and decibel readings for four distances: 1 meter, 2 meters, 4 meters and 8 meters. Include rows for two trials and an average at each distance. After you've taken your decibel measurements at those distances, record your data in the table and calculate your averages. Be sure to write down the units you are using on your decibel meter and tape measure.

4. On your drawing of the space, indicate where your four decibel readings were taken.

5. What is the second location in which your teacher has indicated the experiment will be done? Give a brief description by filling in the following details.

Location:
Length of space:
Width of space:
Height of space (estimated):
Materials in space:
Objects within space:
People within space:
Brief summary of space:

6. Draw a map of the space and its objects (be sure to include the location of the speaker, other objects, a key and a scale bar).

7. Create a table to record your data for the location. Include the distances and decibel readings for four distances: 1 meter, 2 meters, 4 meters and 8 meters. Include rows for two trials and an average at each distance. After you've taken your decibel measurements at those distances, record your data in the table and calculate your averages. Be sure to write down the units you are using on your decibel meter and tape measure.

8. On your map of the space, indicate where your four decibel readings were taken.

Part 2: Questions

Background questions

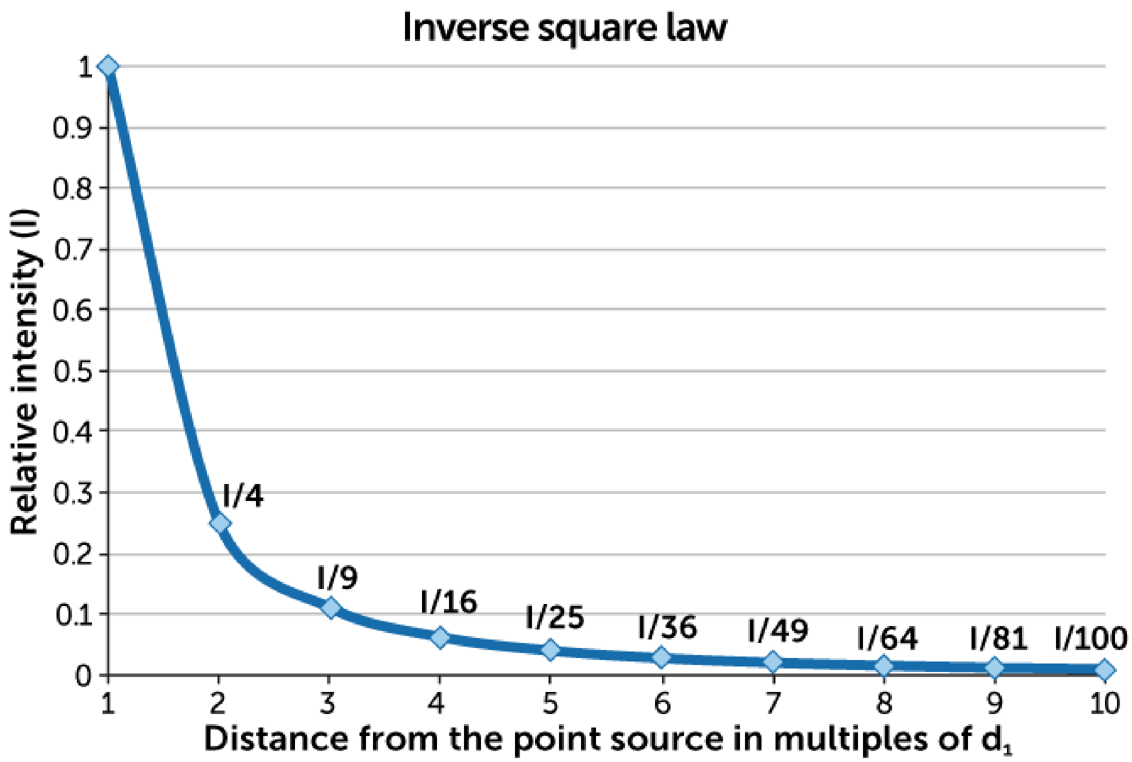
1. Sound waves are created by vibrations. The sound travels as particles crash into each other. What types of materials can sound travel through?

Sound can go through air, water and solids — anything that has molecules close enough to easily collide.

2. Why do you think your teacher played the same sound (same pitch and volume) for each trial in each space?

Changing the pitch or volume would add variables, making it difficult to compare how sound travels in one space versus another.

3. As sound travels in an open space, it spreads out in all directions. The energy twice as far from the source is spread over four times the area, therefore the sound wave has one-fourth of the original intensity. In an idealized space, sound dissipation follows the inverse square law. A graph of the law is shown below.



From the graph, describe the equation of the inverse square law. How would you express the intensity of the sound (I) at some distance (d_2) relative to an initial distance (d_1)?

The inverse square law states that the intensity of sound (I) at some distance (d_2) is $1/(d_2/d_1)^2$.

4. Based on the graph and your equation for the inverse square law, at what distance would you expect the intensity of the sound to be 25 percent of that at the original distance (d_1), 50 percent and 75 percent? Express your answers in terms of d_1.

I would expect the intensity to be 25 percent of the initial reading at about $2d_1$.
I would expect the intensity to be 50 percent of the initial reading at about $1.41d_1$.
I would expect the intensity to be 75 percent of the initial reading at about $1.155d_1$.

5. The intensity level of a sound is expressed in decibels (dB). To estimate the theoretical intensity level in decibels at specific distances according to the inverse square law, you can use the following equation: $I_2/I_1 = [d_1/d_2]^2$, where I_1 is the intensity level in decibels at d_1, or distance 1, and I_2 is the intensity level in decibels at d_2, or distance 2. Using the given equation or a decibel calculator ([this Hyperphysics page]) from Georgia State University has a decibel calculator), find the theoretical intensity levels in decibels for the sound at 2 meters, 4 meters and 8 meters from its source, based on your initial decibel measurement at 1 meter. Complete the calculations for both of your spaces.

Answers will vary based on the initial decibel reading at 1 meter, but each doubling of the distance will drop the intensity by about 6 decibels.

6. How did your decibel readings in location 1 compare to the decibel readings predicted by the inverse square law calculations? Be sure to say whether the values were different and by how much.

Answers will vary. Students might emphasize a difference or they might point out that, though the values differed somewhat, they weren't too far off. Students might see a pattern similar to that predicted by the inverse square law. Depending on the particulars of the space, students might see a faster drop in intensity level than the inverse square law predicts (because of energy lost due to heat and absorption) or a slower drop (if nearby surfaces are highly reflective).

7. Why do you think your readings at location 1 differed from the theoretical predictions made by the inverse square law?

The inverse square law is a theoretical idea that doesn't apply exactly to real-world spaces. In real-world spaces, there is background noise, energy lost due to heat, absorption and reflection and other factors that cause intensity levels to deviate from the theoretical ideal. Students should point out these factors as well as discussing the idea of experimental error.

8. How did your decibel readings in location 2 compare to the decibel readings predicted by the inverse square law calculations? Be sure to say whether the values were different and by how much.

Answers will vary. Students might emphasize a dramatic difference or they might point out that, though the values differed somewhat, they could still see the pattern predicted by the inverse square law. This room is likely to have more absorption than location 1, which might cause the intensity level to drop faster than predicted by the inverse square law, and perhaps faster than in location 1. Because of more objects, the intensity level might also be more variable across the room.

9. Did your readings in location 2 differ from the predictions of the inverse square law more or less than your readings in location 1? Note any patterns you see in the data.

Answers will vary. Location 2 might differ more than location 1 (with intensity levels dropping more rapidly) because of the greater amount of absorption in location 2. Or, location 2 might simply be more variable. The specific results will depend on the particulars of the spaces and the objects within, including people, as well as any background noise and experimental error.

10. At which distance in location 2 did the intensity level most closely match the predictions of the inverse square law? At which distance in location 2 was there the greatest difference between actual and predicted values? Why do you think this is so?

Student answers will vary but they might point to the distance from the sound source, the location of other talking students, or absorbing or reflecting surfaces between them and the sound source.

11. Do the overall results match your expectations for the two spaces? Why or why not?

Students might say that they expected the intensity level to drop more rapidly in location 2 because of more materials and objects for absorption. Or, they might note that they were next to a reflective surface in one of the locations, which they expected to amplify the sound. Student answers will depend on the particulars of *the space, but they should connect ideas back to the inverse square law, how real-world rooms deviate from that law and how the characteristics of the space affect absorption and reflection and thus the sound intensity level.*

12. If you were tasked with adding a third location to this activity that gave intensity level readings that most closely matched those predicted by the inverse square law, what would be the characteristics of your space? What factors might you consider? What barriers might exist to designing such a space?

Students answers will vary, but they should describe a wide and open space with no objects or people to reflect or absorb the sound. One barrier to realizing the ideal is if the space has to have a floor, it will absorb and/or reflect sound. Advanced students might consider the factors that affect how much energy is lost as heat in proposing a space or might discuss how to minimize experimental error.

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Saving Notre Dame's Sound

Activity Guide for Students: A World of Acoustics

Directions: During this activity, you will be making observations about how the volume of a sound changes as it travels in two different spaces. Use Part 1 of this guide to complete the experiment. Part 2 contains questions that you should answer in groups or at home, depending on your teacher's instructions.

First, you will perform the experiment in an open space. You will need to measure the size of the space, as well as make notes about the materials that cover the space and the number and types of objects, including people, in the space. You will also want to make a map of the space for your reference later — don't forget to include the location of the speaker, as well as a key and scale bar.

Students holding the decibel readers will stand around a speaker as your teacher plays a sound. Create a circle with a radius of 1 meter. When the teacher turns the speaker on, record the decibel meter's reading and your decibel meter's initial distance from the speaker (1 meter).

The value given by your decibel meters will likely fluctuate during use as small changes (such as background noise, the angles the meters are held, the movement of people and so on) affect what intensity of sound reaches the meters. Try to obtain readings that are as stable as possible, or record the value that best approximates a stable reading.

Your team will then slowly and carefully walk the decibel meter directly away from the sound source in a straight line (like outward rays). You will record the decibels for three additional distances: 2 meters, 4 meters and 8 meters. If you have to go around any objects, do your best to approximate the correct distances from the source.

You will record results at least twice at each distance and average the data for that distance.

You will then repeat the procedure (observations, mapping and decibel readings) in the smaller space with more objects.

Part 1: Experiment

1. What is the first location in which your teacher has indicated the experiment will be done? Give a brief description by filling in the following details.

Location:
Length of space:
Width of space:
Height of space (estimated):
Materials in space:
Objects within space:
People within space:
Brief summary of space:

2. Draw a map of the space and its objects (be sure to include the location of the speaker, other objects, a key and a scale bar).

3. Create a table to record your data for the location. Include the distances and decibel readings for four distances: 1 meter, 2 meters, 4 meters and 8 meters. Include rows for two trials and an average at each distance. After you've taken your decibel measurements at those distances, record your data in the table and calculate your averages. Be sure to write down the units you are using on your decibel meter and tape measure.

4. On your drawing of the space, indicate where your four decibel readings were taken.

5. What is the second location in which your teacher has indicated the experiment will be done? Give a brief description by filling in the following details.

Location:
Length of space:
Width of space:
Height of space (estimated):
Materials in space:
Objects within space:
People within space:
Brief summary of space:

6. Draw a map of the space and its objects (be sure to include the location of the speaker, other objects, a key and a scale bar).

7. Create a table to record your data for the location. Include the distances and decibel readings for four distances: 1 meter, 2 meters, 4 meters and 8 meters. Include rows for two trials and an average at each distance. After you've taken your decibel measurements at those distances, record your data in the table and calculate your averages. Be sure to write down the units you are using on your decibel meter and tape measure.

8. On your map of the space, indicate where your four decibel readings were taken.

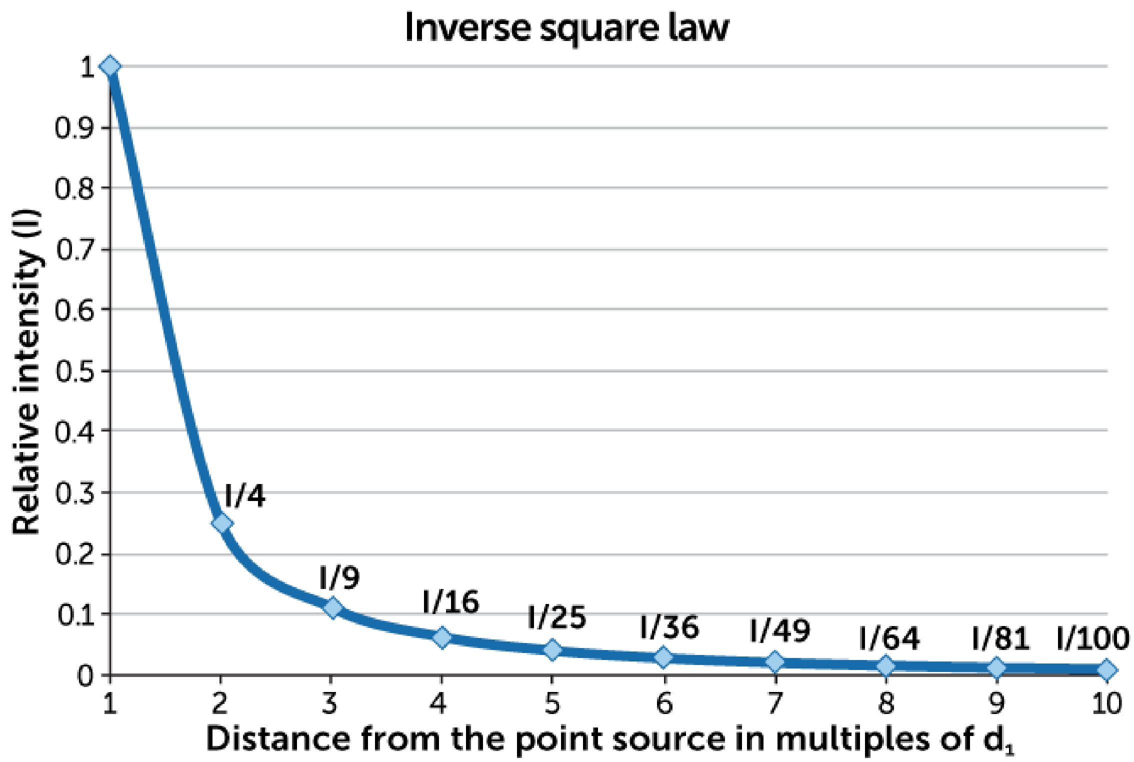
Part 2: Questions

Background questions

1. Sound waves are created by vibrations. The sound travels as particles crash into each other. What types of materials can sound travel through?

2. Why do you think your teacher played the same sound (same pitch and volume) for each trial in each space?

3. As sound travels in an open space, it spreads out in all directions. The energy twice as far from the source is spread over four times the area, therefore the sound wave has one fourth of the original intensity. In an idealized space, sound dissipation follows the inverse square law. A graph of the law is shown below.



From the graph, describe the equation of the inverse square law. How would you express the intensity of the sound (I) at some distance (d_2) relative to an initial distance (d_1)?

4. Based on the graph and your equation for the inverse square law, at what distance would you expect the intensity of the sound to be 25 percent of that at the original distance (d_1), 50 percent and 75 percent? Express your answers in terms of d_1.

5. The intensity level of a sound is expressed in decibels (dB). To estimate the theoretical intensity level in decibels at specific distances according to the inverse square law, you can use the following equation: $I_2/I_1 = [d_1/d_2]^2$, where I_1 is the intensity level in decibels at d_1, or distance 1, and I_2 is the intensity level in decibels at d_2, or distance 2. Using the given equation or a decibel calculator (this Hyperphysics page from Georgia State University has a decibel calculator), find the theoretical intensity levels in decibels for the sound at 2 meters, 4 meters and 8 meters from its source, based on your initial decibel measurement at 1 meter. Complete the calculations for both of your spaces.

6. How did your decibel readings in location 1 compare to the decibel readings predicted by the inverse square law calculations? Be sure to say whether the values were different and by how much.

7. Why do you think your readings at location 1 differed from the theoretical predictions made by the inverse square law?

8. How did your decibel readings in location 2 compare to the decibel readings predicted by the inverse square law calculations? Be sure to say whether the values were different and by how much.

9. Did your readings in location 2 differ from the predictions of the inverse square law more or less than your readings in location 1? Note any patterns you see in the data.

10. At which distance in location 2 did the intensity level most closely match the predictions of the inverse square law? At which distance in location 2 was there the greatest difference between actual and predicted values? Why do you think this is so?

11. Do the overall results match your expectations for the two spaces? Why or why not?

12. If you were tasked with adding a third location to this activity that gave intensity level readings that most closely matched those predicted by the inverse square law, what would be the characteristics of your space? What factors might you consider? What barriers might exist to designing such a space?