



# The Power of Waves

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**Target Grade:** 6<sup>th</sup>-8<sup>th</sup> Grade Physical Science

**Time Required:** 7-11 classes (60 minutes each)

## Standards:

### Next Generation Science Standard:

- MS-PS4-1: Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave.

### Disciplinary Core Idea:

- PS4.A: A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.

### Crosscutting Concepts:

- Patterns
- Cause and effect
- Systems and system models
- Energy and matter

### Science and Engineering Practices:

- Developing and using models
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Engaging in argument from data
- Obtaining, evaluating, and communicating information

### Common Core State Standards Connections:

#### *ELA/Literacy:*

- SL.8.5: Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

#### *Mathematics:*

- MP.2: Reason abstractly and quantitatively.
- MP.4: Model with mathematics.
- 6. RP.A.3: Use ratio and rate reasoning to solve real-world and mathematical problems.
- 7. RP.A.2: Recognize and represent proportional relationships between quantities.

**Lesson Objectives:**

- Students will be able to:
- Model the structure of transverse waves.
  - Describe the relationships between the amplitude, frequency, and wavelength of a wave and the wave's relative amount of energy.
  - Use mathematical representations to demonstrate a wave's relative energy.

**Central Focus:**

In this hands on, exploratory lesson of waves, students will learn about longitudinal and transverse waves. Through mathematical reasoning, students will describe relationships between aspects of waves and a wave's relative amount of energy. Students will use questioning skills to push the lesson along and facilitate engagement and discovery. The use of hands on models will help the students to discover relationships and characteristics of waves and go on to create their own models. With this engaging lesson, it won't be "trough" to get students on your "wavelength"!

Key words: explore, question, engage, model, phenomena, crest, compression, rarefaction, wave, frequency, amplitude

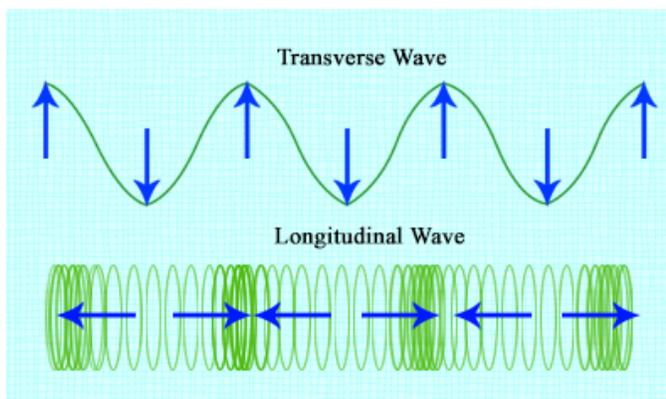
**Background Information:**

A wave is the transport of energy without transporting physical matter. Waves can show a visible disturbance or oscillation in the medium in which they occur; however, waves do not move matter, they only transfer energy.

Longitudinal waves are waves that displace the medium in the same (or opposite) direction as the movement of the wave. As seen in the [linked video](#), when the slinky is pushed forward or pulled back in the same plane, it creates a longitudinal wave. Characteristics of longitudinal wave include: compression, rarefaction, amplitude, wavelength, frequency, and period. Compression refers to the region in a longitudinal waves where the particles are the closest

together, while rarefaction refers to the region in the wave where the particles are furthest apart. In longitudinal waves, amplitude is measured by the maximum displacement (compression or rarefaction) from equilibrium (or resting point). Wavelength refers to the distance between two corresponding points (for instance, from the beginning of one compression to the beginning of the next). Frequency is the number of waves (one wave is the distance from one point to the next) that pass a fixed point in a specific amount of time. A period is simply the amount of time it takes for one wave cycle to complete.

Alternatively, transverse waves are waves for which the displacement of the medium is perpendicular to the movement of the wave. As seen in the linked video, when the slinky is



<https://www.flickr.com/photos/102642344@N02/15278413843>



moved up and down (perpendicular) in the plane, it creates a transverse wave. Transverse waves have many characteristics: crest, trough, amplitude, wavelength, frequency, and period. Crest and trough refer to the most extreme points on the waves. The crest is the maximum, or highest point, and a trough is the minimum, or lowest point. In transverse waves, amplitude is measured by the maximum displacement (crest or trough) from the resting point. Like with longitudinal waves, wavelength refers to the distance between points, often from one crest to the next. Frequency remains the same between longitudinal and transverse waves: the number of waves that pass a fixed point in a specific amount of time. Similarly, a period also remains the same between longitudinal and transverse waves: the amount of time it takes for one wave cycle to complete.

The relationships of characteristics of waves can be identified through several equations. In the following equation, wave frequency is denoted by ( $f$ ) and is measured in Hertz ( $\text{Hz} = 1/\text{s}$ ), wavelength ( $\lambda$ ) is measured in meters (m), wave speed ( $c$ ) is measured in meters per second (m/s), and period ( $T$ ) is measured in seconds (s). The overall formula is  $\lambda = c / f = c \times T$ , which can be manipulated to find different aspects of a wave. For instance, formulas to find frequency are:  $f = 1 / T$  and  $f = c / \lambda$ .

Video URL: <https://www.youtube.com/watch?v=7cDAYFTXq3E>

## Materials

- Post-It Notes
- Chart paper
- Projector & screen
- Teacher computer with speakers
- Access to YouTube
- One copy per student of [“Characteristics of Sound” \(from ck12.org\)](#)
- One writing utensil per student
- Class set of [Dry Erase Pockets](#) or Dry Erase Boards
- Class set of dry erase markers
- Class set of erasers (or, in a pinch, Kleenex tissues)
- [Slinky](#)
- Rope
- Whiteboard
- USB microphone
- [Audacity](#) (a free sound editing program available on Mac or Windows), downloaded on the teacher computer
- One jump rope per group of 3 students
- One student computer (i.e., Chromebook) per group of 2 students (Adobe Flash must be installed/active)
- Internet access for all student computers
- One copy of [PhET “Wave on a String” Worksheet](#) per student
- One copy of [CER worksheet](#) per student

**Instruction**

*PART ONE: Engage and review prior knowledge using an engaging phenomenon, a Driving Question Board, and a formative assessment probe. (2-3 class periods)*

1. Show the following video ([“My PVC Instrument, DRS Talent Show” by Snubby J](#)) with sound.
2. Give each student three Post-It notes. Ask students to write one specific question about the video on each Post-It note.
  - a. *Questions may include: Why are some sounds higher than others? How did he build his instrument? Why did he use rubber mallets to hit the pipes?*
3. Post several sheets of chart paper around the room. Have students sort their questions into specific categories using the chart paper.
  - a. *For example: Questions like “Why are some sounds higher than others?” and “How did the pipes make low sounds?” could be sorted into a category of questions pertaining to pitch.*
  - b. *Note: Students should sort questions themselves! The teacher may serve as a guide to prompt students, but give the class agency in sorting their own questions.*
4. Once questions are sorted into categories, synthesize all the student questions for each category into one class question.
  - a. *For example: Questions in a category pertaining to pitch, like “Why are some sounds higher than others?” and “How did the pipes make low sounds?, could be summarized as “Why do we perceive some sounds as high or low?”*
5. Using the class question for each topic (likely 3-6 total), narrow the focus for this lesson. Explain to students that we will be able to answer more questions prompted by the video (for example, the making of instruments) later, but for the time being we will focus on how volume and pitch work.
6. Explain to students that we will need to review what sound is before we can talk about specific details we had questions about. Pass out one packet of “Characteristics of Sound” (from [ck12.org](#)) per student.
  - a. *Teacher can decide which sections students should complete.*
7. Students can either work individually or with a partner.
8. Discuss some answers as a class and encourage students to ask questions as they move through the packet.
  - a. *Conversation should lead to a discussion about the nature of sound: the vibration of matter. Students should already know that sound needs a medium to travel through (i.e., objects or air), and that all objects that produce sound must first vibrate.*
  - b. *Encourage students to go back to previous sections to change their answers as they discover new information.*
9. Have students store their packets in their science binder for future reference.

*PART TWO: Modeling the structure of transverse and longitudinal waves. (1-2 class periods)*

1. Give each student a dry erase pocket, dry erase marker, and eraser.
  - a. *Note: Put a piece of plain white printer paper in each dry erase pocket for ease of use.*
2. Ask students to draw what they think sound and light look like as they travel from one place to another.
3. Have students show their table group and revise their models as a group.



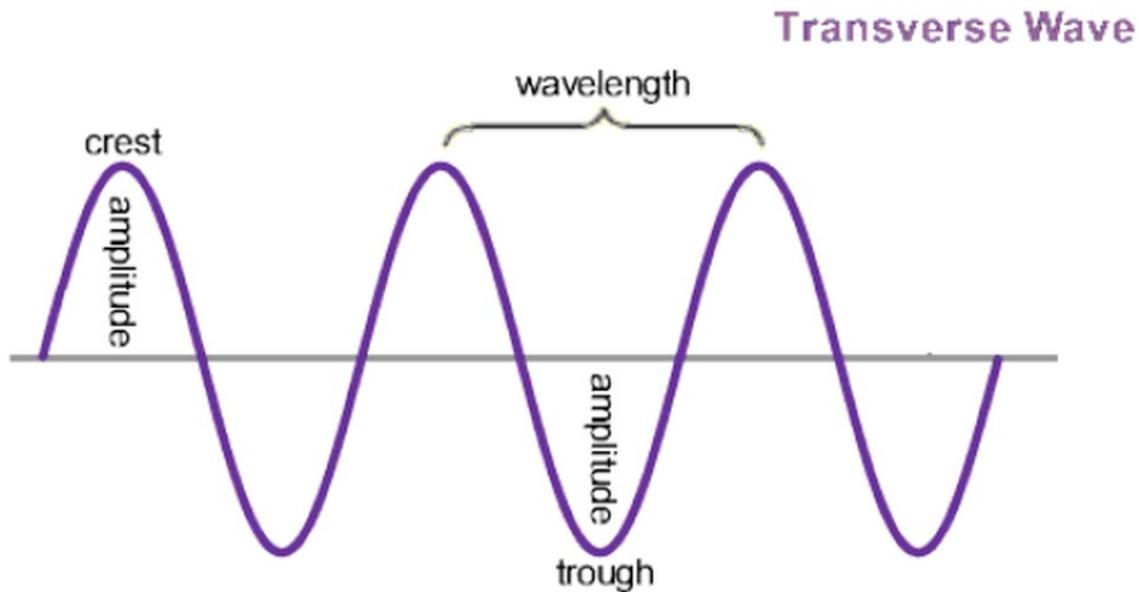
- a. *Note: Dry erase pockets are an excellent way to have students draw models and revise over the course of a lesson. Remind students that their own pocket is their resource for tracking their knowledge throughout the lesson, so as they notice faults in their model, they should erase and redraw accordingly.*
4. Prompt students to discuss the nature of sound and light: that they are waves.
5. Ask students to draw a sound wave on one side of their pocket and a light wave on the other side.
6. Have students show their table group. Discuss similarities and differences between student models as a class.
7. Demonstrate the two types of waves up front.
  - a. Place a slinky on a table at the front of the room. Ask a student to hold one end while you hold the other. Move your end of the slinky toward the student's. Ask students to note observations about the slinky and draw what they see.
  - b. Ask another student to help with this demo. Have them hold one end of a rope while you hold the other. Move the rope up and down. Ask students to note observations about the rope and draw what they see on the other side of their dry erase pocket.
8. Explain to students that these two types of waves are called transverse (rope) and longitudinal (slinky). Ask students to label their models.
  - a. *Note: Teacher should draw these models on the whiteboard along with students. Emphasis is not on telling students exactly what to do, but creating a class model together.*
9. As a class, label the waves with the following terminology.
  - a. Transverse: crest, trough
  - b. Longitudinal: compression, rarefaction
  - c. *English Language Arts connections: Before telling students where each term goes in their model, tell students what terms we will use and ask where they think the word will go. For example, students will likely identify that a trough is used to feed animals, so the trough of a wave must be the bottom portion resembling a bowl. Additionally, compression means something is "smooshed together" (think compression shorts), so it is intuitive to students that the compression part of a longitudinal wave is the "smooshed together" portion, as my students say.*
10. Instruct students to maintain the progress of their models thus far and be ready to add further in the next step.

*PART THREE: Using Audacity to rationalize the relationships between frequency, wavelength, amplitude, pitch, and volume of sound. (1-2 class periods)*

- *Prior set-up: Have [Audacity downloaded](#) to the teacher computer and set up a USB microphone.*
  - *For help using Audacity, visit [this forum](#).*
1. Record a student making a low-pitched sound. (You may highlight the recorded audio, select Effect → Change Pitch, and lower the pitch further.)
  2. Record a different student making a high-pitched sound. (You may highlight the recorded audio, select Effect → Change Pitch, and raise the pitch further.)
  3. Click Tracks → Add New → Mono Track.
  4. Select the high-pitched audio. Cut and paste into the new mono track. You will now see two separate tracks.
  5. Zoom in on the waveforms. Ask students to note observations about the waves.



- a. *Students should notice that the high-pitched sound wave is packed closer together than the low-pitched one.*
6. Revise wave models (on dry erase pockets) by adding “wavelength”.
7. Delete both tracks.
8. Record a student making a loud sound. (You may highlight the recorded audio, select Effect → Amplify to raise the volume further.)
9. Record a different student making a quiet sound. (You may highlight the recorded Audio, select Effect → Amplify to decrease the volume further.)
10. Click Tracks → Add New → Mono Track.
11. Select the quiet audio. Cut and paste the audio into the new mono track. You will now see two separate tracks.
12. Zoom in on the waveforms. Ask students to note observations about the waves.
  - a. *Students should notice that the quiet sound wave is smaller (shorter) than the loud sound wave.*
13. Revise wave models (on dry erase pockets) by adding “amplitude”.
14. By now the class model and student models should resemble this:



*PART FOUR: Using mathematical representations to model the relationship between a wave’s frequency and its relative amount of energy. (2-3 class periods)*

1. Give each group (2-3 students) a jump rope. Have one student hold one end of the rope and another student hold the other end. (If groups include a third student, this student will observe the rope.)
2. Instruct one student to hold the rope at waist level. The other student should hold their end so the rope is parallel with the ground. Then they should move the end up and down to simulate a transverse wave.
3. Ask students to demonstrate a transverse wave with more energy.
  - a. Groups may differ in their representation. Some may move the wave with greater



force up and down, while others may attempt to move the rope faster.

4. Note as a class the differences in groups' models. Discuss how the rope's speed, height, etc. pertain to amplitude, wavelength, and frequency.
5. Ask students to explain and show which waves had the most energy.
6. Split students into groups of two. Each group should have one Chromebook with enabled Adobe Flash.
7. Students will explore the [PhET simulation "Wave on a String"](#). Give partners time to experiment with the simulation for a bit.
  - a. *Ask students to note observations about the behavior of the wave. How does this align with the Audacity model? With the rope model?*
8. Give each student a copy of the PhET "Wave on a String" Worksheet. Instruct students to complete the following:
  - a. Part One: Simply explore the simulation. Play with all the settings, and note any and all observations.
  - b. Part Two: Using the simulation's timer and adjustable frequency, collect data regarding the number of waves that pass a given point.
    - i. *Students should determine that a wave's frequency is simply the number of waves that occur. As they increased the frequency number, more waves passed in the given time period (the waves/min was greater).*
  - c. Part Three: Using the simulation's ruler and adjustable amplitude, make observations and inferences regarding the wave's amplitude, frequency, and wavelength.
    - i. *Students will infer that a wave has a greater amount of energy when it has a greater amplitude. Amplitude is measurable.*
    - ii. *Students note that a wave can have a greater amplitude with increasing wavelength.*

*PART FIVE: Use mathematical, visual, and kinesthetic representations to make and support a claim that a wave's energy is directly proportional to its amplitude. (1 class period)*

1. Give one CER Worksheet to each student. Allow students time to work individually to create and support a claim about the relationship between a wave's energy and its amplitude.
2. Discuss student responses as a class.

### Differentiation

- Allow ELLs / students with IEPs to work with an upper-level partner to label the structure of the waves.
- Give students a modified version of the PhET worksheet that requires less data recording.
- Give ELLs / students with IEPs the following word bank as a paper handout to assist them in labeling the waves. Spelling the terms correctly is not essential.



Crest	Trough	Transverse Wave
Compression	Rarefaction	Longitudinal Wave
Frequency	Wavelength	Amplitude

### Classroom Management

- Call on students equally! Use popsicle sticks or a random number generator to ensure all students get a chance to share their ideas.
- Prompt small group discussion and lead equitable group discussion.
- Allow students to engage with phenomena and models first, before explaining what's happening! Students will need to be monitored to ensure they are using ropes, computers, etc. appropriately, but they need the freedom to explore.

### Extensions

- Allow students to explore additional Sound & Waves PhET Simulations.

### Assessment

#### *Formative Assessment:*

The teacher will check for understanding through student led discussions. The teacher will help facilitate discussion and correct misconceptions, if necessary.

#### *Summative Assessment:*

Students will be scored using the worksheet for Wave on a String PhET simulation and the Amplitude & Energy CER worksheet. Students should be scored on completion, accuracy, and participation.

# Characteristics of Sound

## Lesson 20.1: True or False

Name \_\_\_\_\_ Class \_\_\_\_\_ Date \_\_\_\_\_

*Determine if the following statements are true or false.*

- \_\_\_\_\_ 1. All sounds begin with vibrations in matter.
- \_\_\_\_\_ 2. Sound waves generally travel most quickly through gases.
- \_\_\_\_\_ 3. Sounds can travel through air and water but not through solids.
- \_\_\_\_\_ 4. Sound waves travel more quickly in warm air than cold air.
- \_\_\_\_\_ 5. The amount of water vapor in the air affects the speed of sound through air.
- \_\_\_\_\_ 6. Sounds that are too high in frequency for humans to hear are called infrasound.
- \_\_\_\_\_ 7. As distance from a sound source increases, the area covered by the sound waves decreases.
- \_\_\_\_\_ 8. As the decibel level of sounds gets higher, the pitch of the sounds always gets higher.
- \_\_\_\_\_ 9. The intensity of sound waves is the same regardless of distance from the sound source.
- \_\_\_\_\_ 10. Some animals can hear sounds with frequencies as high as 100,000 Hz.

## Lesson 20.1: Critical Reading

Name \_\_\_\_\_ Class \_\_\_\_\_ Date \_\_\_\_\_

*Read this passage from the text and answer the questions that follow.*

### Sound Waves

All sounds begin with vibrating matter. For example, a guitar string vibrates when it is plucked. The vibrating string repeatedly pushes against the air particles next to it. The pressure of the vibrating string causes these air particles to vibrate. The air particles alternately push together and spread apart. This starts waves of vibrations that travel through the air in all directions away from the strings. The vibrations pass through the air as longitudinal waves, with individual air particles vibrating back and forth in the same direction that the sound waves travel.

Sound waves are mechanical waves, so they can travel only through matter and not through empty space. This was demonstrated in the 1600s by a scientist named Robert Boyle. Boyle placed a ticking clock in a sealed glass jar. The clock could be heard ticking through the air and glass of the jar. Then Boyle pumped the air out of the jar. The clock was still running, but the ticking could no longer be heard. That's because the sound couldn't travel away from the clock without particles of matter to pass the sound energy along.

Sound waves can travel through many different kinds of matter. Most of the sounds we hear travel through air, but sounds can also travel through liquids such as water and solids such as glass and metal. If you swim underwater—or even submerge your ears in bathwater—any sounds you hear have traveled to your ears through water. You can tell that sounds travel through glass and other solids because you can hear loud outdoor sounds such as sirens through closed windows and doors.

### Questions

1. How do sound waves begin and how do they travel?
2. How did Robert Boyle demonstrate that sound waves cannot travel through empty space?
3. Most sounds we hear travel through air. From your own experience, what evidence do you have that sounds can also travel through liquids and solids?

## Lesson 20.1: Multiple Choice

Name \_\_\_\_\_ Class \_\_\_\_\_ Date \_\_\_\_\_

*Circle the letter of the correct choice.*

1. Through which medium do sound waves travel most slowly?
  - a. air
  - b. wood
  - c. glass
  - d. aluminum
2. Assume that sound A has a decibel level of 10 and sound B has a decibel level of 30. How many times louder is sound B than sound A?
  - a. 3
  - b. 10
  - c. 20
  - d. 100
3. What determines the intensity of sound?
  - a. amplitude of sound waves
  - b. frequency of sound waves
  - c. distance from the sound source
  - d. two of the above
4. Compared with a low-pitched sound, a high-pitched sound has sound waves with
  - a. greater intensity.
  - b. higher frequency.
  - c. greater amplitude.
  - d. longer wavelength.
5. Human beings can normally hear sounds with a frequency between about
  - a. 10 and 10,000 Hz.

- b. 20 and 20,000 Hz.
  - c. 20 and 140 Hz.
  - d. 10 and 120 Hz.
6. The speed of sound in air at 20 °C is
- a. 343 m/s.
  - b. 1437 m/s.
  - c. 3850 m/s.
  - d. 4540 m/s
7. The Doppler effect occurs when the sound source
- a. is moving relative to the listener.
  - b. produces sound waves with a frequency above 10,000 Hz.
  - c. starts producing lower frequency sound waves.
  - d. starts producing greater amplitude sound waves.

## Lesson 20.1: Matching

Name \_\_\_\_\_ Class \_\_\_\_\_ Date \_\_\_\_\_

*Match each definition with the correct term.*

### Definitions

- \_\_\_\_\_ 1. how loud or soft a sound seems to a listener
- \_\_\_\_\_ 2. sounds with frequencies above 20,000 hertz
- \_\_\_\_\_ 3. unit of sound intensity
- \_\_\_\_\_ 4. how high or low a sound seems to a listener
- \_\_\_\_\_ 5. transfer of energy from a vibrating object in waves that travel through matter
- \_\_\_\_\_ 6. sounds with frequencies below 20 hertz
- \_\_\_\_\_ 7. measure of the amount of energy in sound waves

### Terms

- a. loudness
- b. infrasound
- c. sound
- d. decibel
- e. intensity
- f. ultrasound
- g. pitch

## Lesson 20.1: Fill in the Blank

Name \_\_\_\_\_ Class \_\_\_\_\_ Date \_\_\_\_\_

*Fill in the blank with the appropriate term.*

1. Sound waves are the type of mechanical waves called \_\_\_\_\_ waves.
2. \_\_\_\_\_ of sound is the distance sound waves travel in a given amount of time.
3. Sound waves travel \_\_\_\_\_ quickly in water than in air.
4. The loudness of sound is determined by the \_\_\_\_\_ of sound waves.
5. The pitch of sound is determined by the \_\_\_\_\_ of sound waves.
6. The frequency of sound waves is measured in the SI unit called the \_\_\_\_\_.
7. Changes in pitch of a police car siren as the car speeds past you are called the \_\_\_\_\_.

# Wave on a String

Visit [this PhET simulation](#) called “Wave on a String”.  
Make sure Adobe Flash is enabled on your browser.

## Part 1: Explore

Play with the simulation! Select any settings you would like. What do you observe?

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## Part 2: Timing Frequency

Before you begin, select the following settings:

- Oscillate
- Medium Damping
- High Tension
- Timer
- Slow Motion

1. Without adjusting wavelength and frequency, observe the oscillating wave. First select Fixed End. Then try Loose End. Finally try No End. What do you observe?

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2. For this step, examine the relationship between a wave’s frequency and the number of waves that occur in a given time period. Keep the wave’s amplitude at 0.75 cm. Using the simulation’s timer, count how many times the first wave’s crest/trough passes the center line in 30 seconds.

Frequency	Number of Waves in 30 sec.	Calculate number of waves / min.
0.50 Hz		
1.00 Hz		
1.50 Hz		

2.00 Hz		
2.50 Hz		
3.00 Hz		

3. In your own words, define frequency. Use evidence from the simulation to support your description.

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## Part 3: Measuring Amplitude

Before you begin, select the following settings:

- Oscillate
- Medium Damping
- High Tension
- Rulers
- Slow Motion

1. Ensure Rulers is selected. Drag the left ruler so the 0 cm mark aligns with the center horizontal line (the origin of the wave).
2. Adjust the Amplitude slider. Try 0.25 cm, 0.5 cm, 0.75 cm, 1.0 cm, and 1.25 cm. What do you observe about the height of the wave?

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3. As you adjusted the amplitude, what did you observe about the wave's wavelength?

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4. As you adjusted the amplitude, what did you observe about the wave's frequency?

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# Amplitude & Energy

You've explored the structure and behavior of waves in many ways so far:

- comparing & contrasting a Slinky (longitudinal wave) and rope (transverse wave)
- creating and revising models of light & sound waves
- demonstrating wavelength and amplitude of sound waves using Audacity (high/low pitch, high/low volume)
- modeling amplitude & frequency using the PhET simulation

**Make a claim regarding the relationship between a wave's amplitude and its relative amount of energy.** Support your claim with evidence using any of the wave representations we used in class. Explain how your evidence supports your claim.

<b>CLAIM</b> <i>What do you think?</i>	
<b>EVIDENCE</b> <i>What specific pieces of information from our class models/simulations support your claim?</i>	
<b>REASONING</b> <i>How exactly does your evidence support your claim?</i>	