Classroom Activities

Waves and Their Applications in Technologies for Information Transfer: Middle School

A Collaboration of the Pasco (WA) School District and the Laser Interferometer Gravitational-wave Observatory (LIGO)

Version 1
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This version of the middle school packet may not be the most up-to-date version that exists. Please check the following url to download the most current version:

https://dcc.ligo.org/LIGO-T1400590/public

For additional information, including teacher professional development related to the packet materials, contact

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Introduction

This packet contains classroom activities and materials designed to address the Disciplinary Core Ideas (DCI's) for standard MS-PS4 in the Next Generation Science Standards. Middle and elementary teachers in the Pasco School District along with personnel at LIGO Hanford Observatory have developed the activities, all of which have been used with Pasco students in grade four and (previous to NGSS) grade six.

This document, the middle school version, contains all of the activities that appear in the elementary version plus additional activities that involve equipment and student questions of a higher level of sophistication. Teachers at both levels can make use of any of the activities from either packet. Middle school teachers might choose to omit some of the simpler activities.

Teachers will see that standard MS-PS4 presents three science and engineering practices two crosscutting concepts. Students inevitably will encounter these elements as they work through the activities, but the packet materials deal explicitly only with the standard's DCI's.

The packet does not provide explicit advice or tools for assessment. Teachers should use their best assessment practices through their instruction on waves.

LIGO provides training on the classroom use of these materials. We strongly encourage teachers to request a workshop for this training. Contact LIGO at 509-372-8248 or at *outreach@ligo-wa.caltech.edu* to discuss possibilities for a wave workshop at your school or at LIGO Hanford Observatory.

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The NGSS Middle School Waves Standard

Page 63, NGSS Standard MS-PS4, Next Generation Science Standards, Volume I. The National Academies Press, 2013

MS-PS4 Waves and Their Applications in Technologies for Information Transfer

PERFORMANCE EXPECTATIONS

Students who demonstrate understanding can:

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. [*Clarification Statement*: Emphasis is on describing waves with both qualitative and quantitative thinking.] [*Assessment Boundary*: Assessment does not include electromagnetic waves and is limited to standard repeating waves.]

MS-PS4-2. Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. [*Clarification Statement*: Emphasis is on both light and mechanical waves. Examples of models could include drawings, simulations, and written descriptions.] [*Assessment Boundary*: Assessment is limited to qualitative applications pertaining to light and mechanical waves.]

MS-PS4-3. Integrate qualitative scientific and technical information to support the claim that digitized signals are a more reliable way to encode and transmit information than analog signals. [*Clarification Statement*: Emphasis is on a basic understanding that waves can be used for communication purposes. Examples could include using fiber optic cable to transmit light pulses, radio wave pulses in Wi-Fi devices, and conversion of stored binary patterns to make sound or text on a computer screen.] [*Assessment Boundary*: Assessment does not include binary counting. Assessment does not include the specific mechanism of any given device.]

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop and use a model to describe phenomena. (MS-PS4-2) **Using Mathematics and Computational Thinking** Mathematical and computational thinking at the 6–8 level builds on K–5 and progresses to identifying patterns in large data sets and using mathematical concepts to support explanations and arguments. • Use mathematical representations to describe and/or support scientific conclusions and design solutions. (MS-PS4-1) **Obtaining, Evaluating, and Communicating Information** Obtaining, evaluating, and communicating information in 6-8 builds on K-5 and progresses to evaluating the merit and validity of ideas and methods. • Integrate qualitative scientific and technical information in written text with that contained in media and visual displays to clarify claims and findings. (MS-PS4-3)	**PS4.A: Wave Properties** • A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. (MS-PS4-1) • A sound wave needs a medium through which it is transmitted. (MS-PS4-2) **PS4.B: Electromagnetic Radiation** • When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (MS-PS4-2) • The path that light travels can be traced as straight lines, except at surfaces between different transparent materials (e.g., air and water, air and glass) where the light path bends. (MS-PS4-2) • A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. (MS-PS4-2) • However, because light can travel through space, it cannot be a matter wave, like sound or water waves. (MS-PS4-2) **PS4.C: Information Technologies and Instrumentation** • Digitized signals (sent as wave pulses) are a more reliable way to encode and transmit information. (MS-PS4-3)	**Patterns** • Graphs and charts can be used to identify patterns in data. (MS-PS4-1) **Structure and Function** • Structures can be designed to serve particular functions by taking into account properties of different materials and how materials can be shaped and used. (MS-PS4-2) • Structures can be designed to serve particular functions. (MS-PS4-3) - - - - - - - - - - - - - - Connections to Engineering, Technology, and Applications of Science **Influence of Science, Engineering, and Technology on Society and the Natural World** • Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations. (MS-PS4-3) - - - - - - - - - - - - - - Connections to Nature of Science **Science Is a Human Endeavor** • Advances in technology influence the progress of science, and science has influenced advances in technology. (MS-PS4-3)

See connections to MS-PS4 on page 147.

Teacher Guidance

The packet activities are designed as stations. Students in groups of three or four will move from station to station. Student groups can do the stations any order, including random order where a group would move to an open station after completion of the current station. The packet includes 22 activities. If all of these are used in the classroom, there will be enough stations to maintain a good work flow for a class of 30 students who are working in small groups. A lesson sequence for using the stations could look like the following. Each day would be a 50-minute session.

- Day one: Establish context, do pre-teaching, introduce students to the stations, provide time for brief student group engagement with each station for familiarization.
- Day two: Finish brief engagement with stations; lead the class to identify important observations and questions that arose from the initial explorations. Develop vocabulary.
- Day three: Ask the student groups for deeper engagement at the stations during which students will record their work on the student handouts.
- Day four: Check for student ideas and questions. Undertake vocabulary development. Provide time for students to complete the stations.
- Day five: Sense-making.

Not all of the stations require equal time for completion. We recommend that teachers not use a standard time interval for student groups at the stations but rather allow the student groups to change stations when they're ready. Readiness can be determined by the completion of the station handout.

Pre-teaching: LIGO and the teacher developers encourage teachers to allow students to make progress on the standard by exploring the wave behaviors that the stations provide rather than by delivering formal instruction about wave properties and wave vocabulary and then using the stations. Consider doing a minimum of pre-teaching. 1) Establish a context for the overall activity (see comments below). 2) Acquaint the students with the logistics of how they will rotate through the stations. 3) Give brief demonstrations of stations that require particular skill or particular care. 4) Allow the students to get started. As the students begin experimenting, teachers will see numerous opportunities to develop concepts and vocabulary based on the observations that the students make and the ideas the students generate.

As part of the pre-teaching, teachers will want to establish a context for the overall activity that helps students answer the question "Why are we doing all of this?" We leave choice of method to the teacher. Teachers might choose to use a KWL chart on waves, or use another strategy to identify what students know about waves and what they'd like to learn about waves.

Conceptual background for teachers: Waves are an instance of periodic motion – a process that happens over and over again in the same way. Periodic motion fills our lives and fills the universe. We're constantly experiencing clocks, sleep cycles, meal cycles, work schedules, bus rides to school, visits to the dentist and a myriad of other life events that are periodic. Nature runs the same way, from vibrations of electrons in atoms to the orbits of planets and the spinning of galaxies. The **period** of a system in periodic motion – the time it takes for the motion to repeat itself -- is a measurement of great importance. What are the periods of the following events?

- A clock cycle (12 hours)
- The bus ride to school (One day (on weekdays))
- Your birthday (one year)
- The Moon's orbit around the Earth: (one month)
- The Earth's Orbit around the Sun: (one year)
- Pluto's orbit around the Sun: (250 years)

Some periodic events happen very quickly, such as the spinning of a car tire traveling at highway speed. Since the period of this motion is a tiny number (a small fraction of a second) we often measure the **reciprocal** of the period, which is called the **frequency** of the motion – the number of times it happens per second. Once cycle per second is one **Hertz**.

- A car tire might rotate with a period of a tenth of a second. The frequency of the rotation would be 10 Hertz (Hz).
- Sound waves vibrate with periods of hundredths or thousandths of a second. Their frequencies are in the hundreds or thousands of Hz.
- Visible light waves vibrate with periods of trillionths of a second. Their frequencies are in the trillions of Hz.

A system in periodic motion will transfer energy to its environment in the form of **waves**. We call the environment the **medium**. When an earthquake occurs, vibrations at the epicenter move into the surrounding material (the medium) in the form of seismic waves. When the wind blows over the ocean, vibrations move into the surrounding water (the medium) in the form of water waves. When our vocal cords vibrate, these vibrations move into the surrounding air (the medium) in the form of sound waves. When electrons in atoms vibrate, these vibrations move into the surrounding electric field as light waves. Waves possess periods and frequencies, but they also possess a **wavelength**. The **speed** at which a wave moves through a medium equals the product of the frequency and wavelength of the wave. *(Note: Don't confuse frequency (the rate at which the wave cycles) with speed (the rate at which the wave moves through the medium away from the source).*

Waves fall into two main categories that are easy to visualize with a Slinky. **Transverse** waves vibrate back and forth in a direction that's perpendicular to the direction of their forward motion. **Longitudinal** or **compression** waves vibrate back and forth in a direction that's the same as the direction of their forward motion. We use **amplitude** to characterize the extent of the vibration. Here's where descriptors become important. A student might shake a Slinky with large shakes and say "These are big waves." Another student might shake the Slinky slowly and say "These are big waves." The first student would mean amplitude while the second would mean wavelength. Prior to helping students develop these formal vocabulary terms, teachers might find it useful to encourage students to use the word "tall" in the first instance and "long" in the second rather than "big" for both.

All waves undergo certain behaviors such as **reflection** (bouncing off an obstacle) and **refraction** (changing their direction because of a change in some property of the medium). Although we usually think about reflection and refraction in the context of light, all waves can exhibit these behaviors.

Waves can **transmit information** from one place to another. The frequencies of sound waves give rise to the properties of pitch and tone and allow us to transmit information as sound. The frequencies of visible light give rise to color, another mechanism of information transfer.

Cell phone technology adds sound information (waves of relatively low frequency) onto light (radio waves or microwaves – invisible forms of light). At the receiving end, the high-frequency microwaves essentially get stripped away, leaving the frequencies of the original sounds to be converted to sound waves through the speaker of the receiving phone. Whether by sending sound information as light through the air or as light through optical fiber, light-based information transfer takes advantage of the fact that light waves travel immensely faster than sound waves and much faster than electric currents.

These days most information transfer happens digitally. When we speak into our phones, our sound waves of continuously varying frequencies are turned into strings of digital "bits" – collections of zeroes and ones that encode the original frequency content. Computers don't understand continuously varying values; they only understand bits. The move to digital communications provides engineers with a more efficient information transfer method that allows for computerized optimization and control.

LIGO Field Trips

LIGO Hanford Observatory regularly hosts field trips for school groups of all ages. Trips provide an opportunity for students to learn about LIGO's search for gravitational waves, to meet and interact with a LIGO scientist or engineer, and to personally explore light, gravity, waves and the galaxy through our hands-on exhibits and activities. LIGO encourages schools to bring students to the Observatory on a field trip as either an introductory wave experience or a culminating activity for the wave lessons.

LIGO Field Trip Q & A

What are the dates/times that LIGO could host a field trip?	LIGO is available on any weekday as long as our calendar is clear. Check the listing on our tours page to see what we've already scheduled.
What will be the cost to my school for a visit?	We offer field trips at no cost through our support from the National Science Foundation
How much notice must I give you?	Several weeks' notice is typical, but short notice is often possible. In the spring we host several trips a week, so earlier notice gives you better date selection.
How long does a typical visit last?	We recommend a minimum visit of 2 hours, and 3 - 3.5 hours is the most common visit length (which includes 30 minutes for brown-bag lunches that students bring along).
How many adult chaperones should we bring?	The more chaperones the better as far as LIGO is concerned. We've noticed that students tend to extract more value from field trips in the presence of friendly adult guidance and focusing. LIGO requests roughly one adult for every ten students. Chaperones need not possess technical backgrounds.
What sorts of things will we do on the visit?	The standard field trip components are a welcome and introduction, some hands-on time with our exhibits, a discussion about LIGO from one of our scientists, lunch, and a walking tour of the site including a visit to the control room. We welcome suggestions for maximizing connections to your

science teaching. Do you teach an earth science unit? Seismic behavior intimately relates to our interferometers. Chemistry? LIGO houses one of the world's largest ultra-high vacuum environments. Geometry? Our interferometers are, in one sense, huge surveying devices. The theory on which LIGO is based deals with the geometry of curved bodies (curved space in our case).

How can I connect a LIGO field trip to my classroom instruction?	LIGO activity cuts across many science, math and engineering disciplines. Our major themes are gravity, geometry, light, wave behavior/periodic motion, the nature and scale of the universe and the nature of scientific discovery. Our exhibits and activities provide opportunities to address a variety of NGSS Standards.
What can I do to help students engage strongly with LIGO?	The "LIGO Explorer" field trip packet that students will receive at LIGO will help guide the students through the hands-on exhibits and activities. Please consider making the packet a class assignment. Students who realize the need to respond to the questions in the packet generally process the exhibits more successfully.
What sort of pre-and post-field trip activities are available for my students?	LIGO offers several Web and print classroom resources to help prepare kids for a field trip to the Observatory and to engage in additional LIGO-related learning back in the classroom after the trip. Check LIGO’s Pre-Field Trip and Post-Field Trip web pages to find links to these resources.
Won't your science go over the heads of my students?	We strive to design field trips that match the levels and backgrounds of our guests. Hands-on explorations with our exhibits and activities allow students to build a visual and tactile framework for interpreting the science of LIGO.
OK, you've talked me into it. How do I schedule a trip?	Call our outreach personnel at 509-372-8248 or send an email to outreach(at)ligo-wa.caltech.edu. We would be pleased to host a visit from your class!

Find LIGO field trips on the Web at http://www.ligo-wa.caltech.edu/field_trips.html .

Activity Descriptions Grouped by NGSS DCI's for MS-PS4

PS4.A: Simple wave properties

Waves on a Slinky
Two students, one on either end of the Slinky, take turns making transverse and compressions waves on the Slinky.

Waves on a rope
Two students, one on either end of the rope, take turns making transverse waves on the rope.

Waves in a rain gutter
Students push a plunger in one end of a filled rain gutter. Small corks bobbing on the surface show that the water doesn't move forward as the waves move forward.

Waves in a ripple tank (or large cake pan)
Students observe circular and linear waves moving through water at different frequencies.

Waves on pencils
Students observe transverse waves moving across a collection of pencils that are strung together.

PHET wave applet
Students use a computer simulation to manipulate the wavelength and frequency of waves.

** Bill Nye video: Waves
A discussion and demonstrations of basic wave properties

PS4.A: Sound

A vibrating ruler
Students twang a ruler on the edge of a table to make sounds of different frequencies

A vibrating speaker
Students control the frequency of a signal generator that's sending a signal to a speaker. Students observe the behavior of the speaker.

Measuring sound waves on a computer
Students make tuning forks vibrate and look at a graph on a computer display to see the wave pattern.

Sound waves – vibrations of air
Using a quiet blow dryer, students blow air over a set of soda bottles filled to different heights with water.

A Pair of Tuning Forks
Students tap one tuning fork that sits next to another and observe the sound waves that are produced by the second fork.

Sound waves through metal
Students roll a ball bearing down a ramp and collide it with a line of ball bearings.

PHET sound applet
Students use a Web applet to manipulate the frequency and wavelength of sound waves

** Bill Nye video: Sound
A discussion and demonstrations of sound waves and their properties

PS4.B: Light and matter

Reflections from a flat mirror
Two students stand in various positions in front of a flat mirror and note the positions at which they can see the reflections of each other

Reflections from a curved mirror
Students stand at various distances straight in front of a curved mirror and note the appearance of their reflections at different distances

Light through curved lenses
Students look through lenses that curve inwards and lenses that curve outwards and note the appearance of the objects they see.

Light through prisms
Students observe refraction and dispersion through prisms

Light through a diffraction grating
Students observe diffraction through a grating

PS4.C: Information Technologies and Instrumentation

Light through fiber optic cable
Students shine a light into one end of a length of fiber optic cable and observe the other end of the cable.

Sound through a tin can telephone
Two students send sound messages through a wire that connects a pair of tin can telephones.

Vibrations of light at frequencies of sound
Students shine a laser onto a vibrating mirror and observe the patterns of reflections.

Transferring sound onto light
Students observe that the signal from a MP3 player can be converted to light and transmitted to speakers. Students observe the result when the light beam becomes blocked.

** The videos are supplemental instructional resources; we don't use these as stations

Activity setup instructions, additional notes and materials lists

Waves on a Slinky

Two students, one on either end of the Slinky, take turns making transverse and compressions waves on the Slinky.

Setup: The Slinky works best on a tile floor or on a smooth table top of adequate size. A carpeted floor makes a lot of friction.

Notes:

- One student should hold her end still and let the other student either swing her end (for transverse waves) or push her end (for compression waves.
- We all know how easy it is to tangle up a Slinky
- If a pair of students stretches the Slinky taut and one student lets go, injury can result.
- While double-length Slinkies available from science suppliers are great for certain demonstrations, they tangle so easily that we don’t recommend these for the Slinky station. Regular length Slinkies will survive longer.

Item	*Source*	*Item Number*	*Cost*
Slinky	ToysRus	Slinky	5.00

Waves on a rope

Two students, one on either end of the rope, take turns making transverse waves on the rope.

Setup: Two students spread out the rope. One holds her end still while the other makes transverse waves.

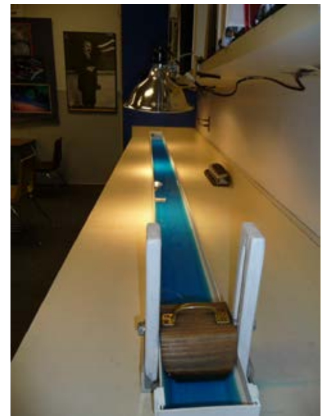
Notes:

- The type of rope really makes a difference in this experiment. A rope that lacks the proper stiffness doesn’t transmit the waves very well. We list relatively heavy rope below; you might want to try some different grades to find your preference.

Item	*Source*	*Item Number*	*Cost*
20’ 5/8” nylon rope	Lowe’s	349190	13.60

Waves in a rain gutter

Students push a plunger in one end of a filled rain gutter. Small corks bobbing on the surface show that the water doesn't move forward as the waves move forward.



Setup:

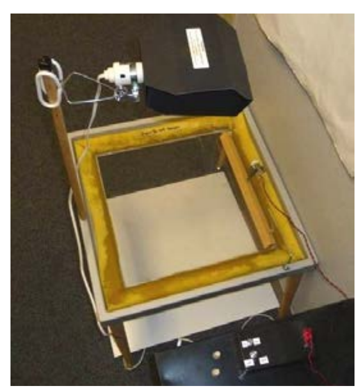
- Snap the end caps onto the gutter (surprisingly hard to do)
- Lay the gutter on a tile floor and fill it to about 2/3 height with water. You might find that a bit of food coloring in the water makes the waves easier to see, but this somewhat depends on the room lighting.
- Trim a sponge or a small block of 4"x4" wood so that it fits the contour of the gutter as you push the object down to make a wave.
- Drop a couple of small corks at various places along the gutter to serve as buoys.

Notes:

- What *shouldn't* happen at this station is for the students to create currents in the water by pushing the water horizontally. Students should makes waves, not currents, by pushing the plunging device up and down and not sideways. Some sort of restraint taped or glued across the top of the gutter near the end might help to confine the plunger and limit its sideways motion. (Of course you might invite them to make currents as well as waves to visualize the difference).

Item	*Source*	*Item Number*	*Cost*
10' 4.5" plastic gutter	Lowe's	12066	6.47
Two 4.5" gutter caps	Lowe's	12068	$2.97 x 2
Small corks (size #4)	Amazon.com	Corks	8.99

Waves in a ripple tank (or large cake pan)



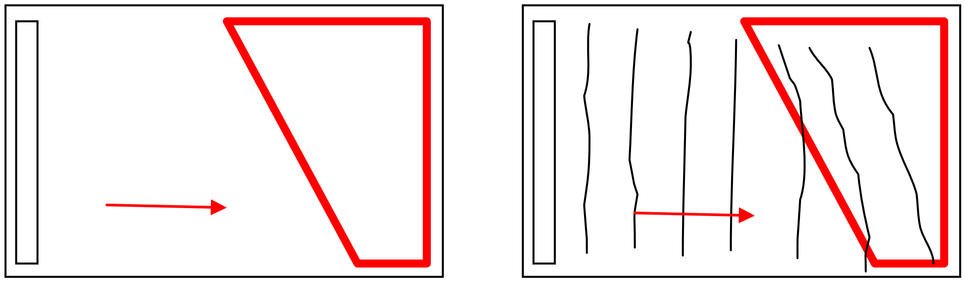
Students observe circular and linear waves moving through water at different frequencies.

Setup:

- If you purchase a ripple tank apparatus from a supplier, the apparatus will come with assembly instructions. The setup takes some time and is a bit complicated, but the results are very good if you can obtain a

suitable level of performance.
- **OUR PREFERRED SUBSTITUTE:** A large shallow cake pan can serve the same purpose. Students will need to generate waves by hand using an eye dropper for circular waves and a piece of wood for linear waves. We found that the polished reflective bottom surface of the cake pan made the waves hard to see. Consider painting the bottom of the dish with a matte finish, or lay a piece of thin dull material on the bottom (wood and some types of plastic might float). We eventually found a pan at a restaurant supply with a brushed aluminum finish that was much less reflective than smooth steel.

Notes:
- This station provides a good opportunity to model waves that move out in circles versus waves that move in a uniform direction. Reflection is obvious in each instance.
- Both the ripple tank and the cake pan can demonstrate **wave refraction** (the bending of waves). You'll need to cut a piece of plywood in a way that creates an angle for incoming waves. Weight the corners of the wood piece so that it sinks. The depth of the water on the wood should be about half of the depth in the remainder of the pan. When the waves reach the depth change, you'll see the wave path bend to follow the angle of the wood. This can serve as a model of what happens to light when the light goes travels from air into the glass of a prism or lens. See the diagrams below (top view).

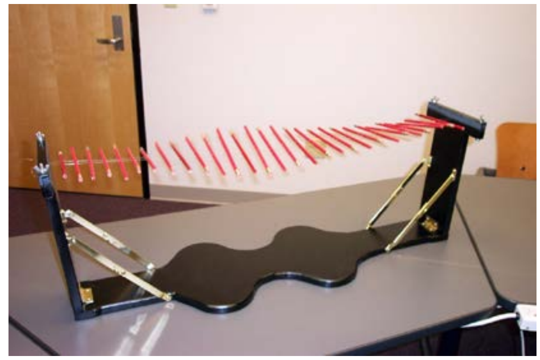


- Safety: One of the drawbacks of the commercial ripple tank kit is that the light source becomes very hot. It's shielded in an encasement, but some teachers elect to avoid the apparatus because of this concern

Item	*Source*	*Item Number*	*Cost*
Ripple tank kit	Carolina	754180	350
Ripple tank light	Carolina	754185	56
Small corks (size #4)	Amazon.com	Corks	8.99
OR . . .			
16" x 24" x 2" cake pan	Amazon.com	Parrish	37.21

Waves on pencils

Students observe transverse waves moving across a collection of pencils that are strung together.



Setup:

- Commercial units can be purchased for as low as roughly $150. We haven't used one of these and we can't comment on the durability.
- Substitute: LIGO's version (photo) consists of pencils that are strung on two parallel horizontal runs of fishing line. Ours is hard to make because each pencil needs a pair of precision-drilled holes to take the loops of fishing line, but ours has proven to be durable.
- Another substitute: A less durable but much easier option involves laying out a line of 1" masking tape on a table, sticky side up. Now lay pencils across the tape. Space the pencils by about an inch. Center the pencils on the tape strip but alternate the side that holds the eraser. The mass of the pencils isn't symmetric about the center point – the eraser side is heavier. By alternating them on the tape you'll help the finished apparatus to lay flat. Finish by laying another tape strip over the top of the pencils so you form a tape sandwich with the pencils in between. You can hang the device vertically from the ceiling or figure out a way to mount it horizontally.

Notes:

- The pencil apparatus makes very nice twisting waves. The wave speed is low, making reflection and wavelength easy to see. Wobbling the pencil at the end quickly gives a higher frequency and shorter wavelength. A lower frequency gives a longer wavelength.

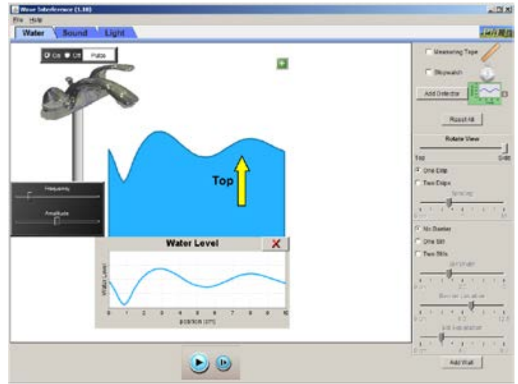
Item	*Source*	*Item Number*	*Cost*
Wave machine	ShopAnatomical.com	3B-U8431805	151
OR . . .			
60 pencils	Staples	476919	8.45
1" masking tape	Staples	468413	8.99

PHET wave applet

Students use a computer simulation to manipulate the wavelength and frequency of waves.

Setup:

- Find the simulation at http://phet.colorado.edu/en/simulation/wave-interference.
- You must verify that the simulation will run properly on the system that the students will use. The type and version of browser, school district security settings, presence or absence of add-ons and other variables can complicate your ability to play the simulation.

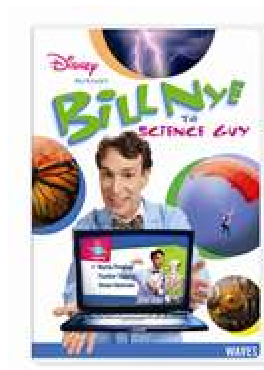


Notes:

- Like all PHET simulations, this one is feature-laden. For this exercise we prefer to use it simply, with a single drop of water. We like the side view with the graph showing. Students can (will) explore different viewing options. Note that the frequency and amplitude can be controlled with sliders.

Item	*Source*
PHET wave applet	http://phet.colorado.edu/en/simulation/wave-interference.

<u>Bill Nye video: Waves</u>



A discussion and demonstrations of general wave properties

Setup:

- Show the DVD

Notes:

- The video provides an opportunity for clarification of learning that the students have accomplished at the stations. We recommend that the video follow the hands-on station experiences rather than precede them.

Item	*Source*	*Item Number*	*Cost*
Bill Nye: Waves	www.dep-store.com	77A58VI00	14.99

<u>A vibrating ruler</u>

Students twang a ruler on the edge of a table to make sounds of different frequencies

Setup:

- Several plastic rulers (in case of breakage) and the edge of a desk.

Notes:

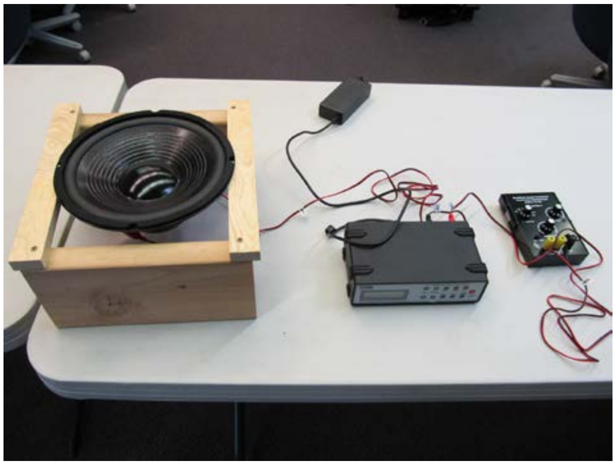
- Teachers might wonder why such a bland activity would be included. It actually offers a nice connection between frequency and pitch. Twang a longer length and you can hear a low tone and see a low frequency. Shorten the twang length and you'll see a higher frequency and hear a higher pitch. The connection between a vibration of higher frequency and the hearing of higher pitch is a key understanding for sound waves.
- Be careful not to purchase the newer flexible rulers!
- This is a station that doesn't take as long as some of the others to complete.

Item	*Source*	*Item Number*	*Cost*
Plastic rulers	Staples	382725	1.49 ea

<u>A vibrating speaker</u>

Students control the frequency of a signal generator that's sending a signal to a speaker. Students observe the behavior of the speaker.

Setup:



- Use an Elenco function generator to make the wave signal. Set the function generator's course adjust on 100 (Hz). You can use the fine adjust to vary the frequencies between 10 and 100 Hz. Connect cables between the function generator and a Radio Shack amplifier. Connect the output of the amplifier to a large audio speaker.
- Slice drinking straws lengthwise into narrow slices. Tape the straw slices to the edge of the speaker cone so that the straws extend outwards from the speaker all the way around the circle. The motion of the straws will exaggerate the vibrations of the speaker cone. (The straws don't appear in the photo)
- Experiment with the function generator frequency. At low frequencies you should be able to find frequencies at which the straws really flop up and down (these are resonant frequencies of the mechanical system).

Notes:

- This station makes clear the relationship between vibrations and sound.

- It’s one of several stations that’s a bit expensive, requires some labor and is tricky to set up (especially the first time), but there’s a big payoff in student interest if you can get good performance from the components.

Item	*Source*	*Item Number*	*Cost*
Function generator	parts-express.com	320-118	41
Audio amplifier	Radio Shack	55062118	110
Audio speaker	Am. Sci. & Surplus	41350P1	25
Connector wires	parts-express.com	360-150	4

<u>Measuring sound waves on a computer</u>

Students make tuning forks vibrate and look at a graph on a computer display to see the wave pattern.

Setup:

- For this station you will need a PC (either desktop or laptop) with an external microphone. On the PC you will load the software named Visual Analyzer. Students will ring tuning forks, hold the forks near the microphone and watch the pattern of sound waves on the screen.

Notes:

We strongly recommend that teachers spend some time at this station making sure that they know how to gain the best results from the system

Tuning forks should only be struck with the rubber end of the mallet that comes with the set, or on something soft like the back of a shoe. The forks will wear out when struck on hard surfaces.

- The microphone will only receive the sound from a tuning fork when the fork is held with its long edge facing the microphone directly. Alternately stated, observe the direction that the forks vibrate. Make sure to hold them in front of the microphone so that the direction of the vibration goes straight into the microphone and does not move out in the perpendicular direction.

Item	*Source*	*Item Number*	*Cost*
Visual Analyzer	www.sillanumsoft.org	Choose the version	Free
PC microphone	OfficeSupply.com	IGRME92884	10.25
Tuning fork set	Flinn Scientific	AP6982	64

Sound waves – vibrations of air

Using a quiet blow dryer, students blow air over a set of soda bottles filled to different heights with water.

Setup:
- Drink a six-pack of Weinhard's orange cream soda to empty the bottles. You can mount the bottles in wood as in the photo or use them in the six-pack container.
- Leave one bottle empty and fill the rest with progressively greater amounts of water.
- If the hair dryer is quiet enough, it serves as a good source of air across the bottles.
- Safety: Find a hair dryer that has a cool air setting
- Safety: Make sure that the bottles are secured against tipping.

Notes:
- Students can make a helpful comparison between the behavior at this station and the behavior of the tuning forks.
- Tuning forks and partially filled soda bottles are resonators – systems that vibrate at certain natural frequencies. At this station the air column in the bottle on top of the water vibrates when rapid air moves sideways across the top of the bottle.

Item	*Source*	*Item Number*	*Cost*
Soda bottles	Grocery	Soda, not beer	5
Quiet hair dryer	BB & Beyond	RV484	20

A pair of tuning forks

Students tap one tuning fork that sits next to another and observe the sound waves that are produced by the second fork.

Setup:
- Place the two open ends of the wooden holders near each other but not touching.

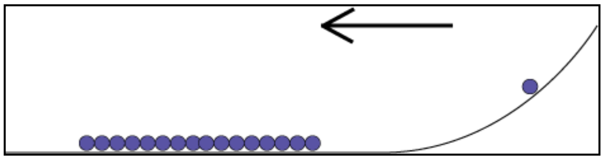
Notes:
- These devices are expensive but worth it, we would say. Many students in the pilot groups found this to be the most captivating experiment

Item	Source	Item Number	Cost
Resonant tuning forks	Flinn Scientific	AP5724	122

<u>Sound waves through metal</u>

Students roll a ball bearing down a ramp and collide it with a line of ball bearings.

Setup:



- Purchase a molding strip at a hardware store. The surface needs to be a curved channel into which a ball bearing will fit and roll.
- Elevate one end of the strip, leaving at least half of the strip flat on a table top.
- Line up a series of ball bearings on the flat portion so that they touch each other.
- Roll a single ball bearing down from the elevated end.
- If you tune the station to optimum performance, the rolling bearing will hit the bearing at the one of the line of bearings and the bearing at the opposite end immediately will pop away from the group. It's a challenge to obtain optimum performance.

Notes:

- When working as intended, this station illustrates sound waves traveling through metal. When the ball immediately pops off the far end the line at the time of the collision, students will realize that the collision energy must have transferred very quickly through the line of bearings. At the speed of sound, in fact. The collision causes a sound wave to travel through the bearing line.
- The station also illustrates the role of the medium in the propagation of sound

Item	Source	Item Number	Cost
Bearing track (8' cove molding)	Lowe's	310622	4
10-pack ¾" bearings	Amazon.com	Avler	8.75 x 2

<u>PHET sound applet</u>

Students use a computer simulation to manipulate the wavelength and frequency of waves.

Setup:

- Find the simulation at http://phet.colorado.edu/en/simulation/sound
- You must verify that the simulation will run properly on the system that the students will use. The type and version of browser,

school district security settings, presence or absence of add-ons and other variables can complicate your ability to play the simulation.

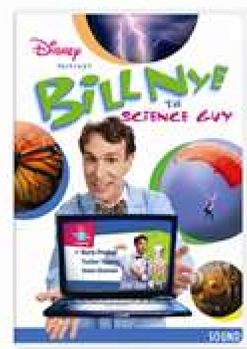
Notes:

- Start on the "Listen to a single source" screen. Later, move to the measurement screen
- The simulation might not make it clear to students that sound travels as compression waves rather than transverse waves.

Item	*Source*
PHET wave applet	http://phet.colorado.edu/en/simulation/sound

<u>Bill Nye video: Sound</u>

A discussion and demonstrations of the behavior of sound waves



Setup:

- Show the DVD

Notes:

- The video provides an opportunity for clarification of learning that the students have accomplished at the stations. We recommend that the video follow the hands-on station experiences rather than precede them.

Item	*Source*	*Item Number*	*Cost*
Bill Nye: Waves	www.dep-store.com	77A34VL00	14.99

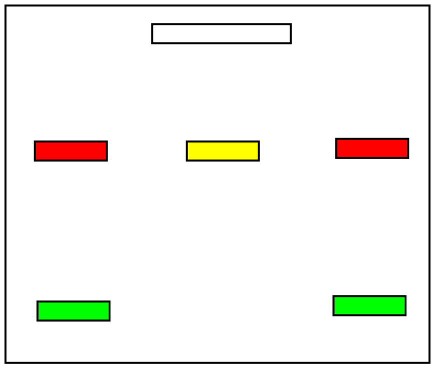
<u>Reflections from a flat mirror</u>

Two students stand in various positions in front of a flat mirror and note the positions at which they can see the reflections of each other

Setup:

- Find a large flat mirror and position it so that students will not knock it over. A closet door mirror will work well by minimizing the amount of stopping that's needed for students to see each other's faces.
- You'll need to use three colors of electrical tape to make marks on the floor where students will stand. Place a yellow tape straight in front of the mirror and four feet away. Place a red

tape four feet to the left of the yellow tape. Place another red tape four feet to the right of the yellow tape. The two red tapes and the yellow tape should sit on a line that's parallel to the face of the mirror. Now place two green tapes eight feet away from the red tapes going away from the mirror. The two green tapes should line up with the two red tapes.



Notes:

- The key realization at this station relates to the geometry of the reflections. It's a very simple station, but the question of why certain reflections appear and others don't will provide an opportunity for thinking and questions.

Item	*Source*	*Item Number*	*Cost*
Large flat mirror	Lowe's	471106	15
Colored electric tape	Lowe's	291607	5.18

Reflections from a curved mirror

Students stand at various distances straight in front of a curved mirror and note the appearance of their reflections at different distances

Setup:

- Place a black tape mark on the floor so that the student will stand on it and be very close to the mirror. Place a red tape mark about ten feet away from the mirror. This experiment is hard to do because students tend to lose their reflection as they back away from the mirror. Most curved cosmetic mirrors come on stands that allow the mirror to tilt, which can further complicate students' efforts to see themselves at a distance.

Notes:

- If you can make this station work reliably, students will be able to connect the result here to the result of the curved lens station.

Item	*Source*	*Item Number*	*Cost*
Concave cosmetic mirror	Walmart	0030997104627	6
Colored electric tape	Lowe's	291607	5.18

Light through curved lenses

Students look through lenses that curve inwards and lenses that curve outwards and note the appearance of the objects they see.

Setup:

- Ensure that the students can't break the lenses through normal use. Consider wrapping the circumference of the inward curving lens with a number of wraps of duct tape to cushion the glass. The outward curving lenses (magnifiers) are plastic.

Notes:

- The comparison between the images created by the outward curving and inward curving lenses are quite striking. Help students notice the difference between the ways that the lenses curve.

Item	*Source*	*Item Number*	*Cost*
Jumbo magnifying glass	ToyStore-USA.com	LER-2775	6
Large concave lens	Surplus Shed	L11175	8

Light through prisms

Students observe refraction and dispersion through prisms

Setup:

- Students will hold the prisms lengthwise in front of their eyes and look through them. The refraction effects are startling.
- If the Sun is out and windows are available, students can hold the prisms to the side and try to see the dispersed rainbow pattern on a counter or other surface.
- Safety – Be very careful about taking the prisms outside.

The glare of the Sun from the prisms faces can be very severe.

- Glass prisms will break if dropped, of course. Perhaps a greater concern is the chipping that will occur through regular use if the devices aren't handled with continuous care. Acrylic prisms are safer but they scratch easily.

Notes:

- The standard asks students to develop an understanding of the varying amount of refraction as a function of wavelength of the light. The prisms provide an avenue to this outcome.

Item	*Source*	*Item Number*	*Cost*
4.5" prism	Scientificsonline.com	3052451	13

Light through a diffraction grating

Students observe diffraction through a hand-held grating

Setup:

- Students will hold the grating in front of their eye. They should avoid touching the grating surface; it will smudge.
- If the Sun is out and windows are available, can see the visible solar spectrum through the grating by looking at a portion of the sky away from the Sun or by looking at a white wall that's reflecting the Sunlight. Students will need to avoid looking directly at the Sun, of course.
- Students also should look at the diffraction pattern from interior lights such as fluorescent lights. Unlike the continuous solar spectrum in which the rainbow colors blend together, the fluorescent light spectrum is discreet – the colors are separated from one another.
- The diffraction grating gives interesting results with different colors of lights if any are available. Yellow sodium street lamps, neon signs and green exit lights all provide interesting comparisons to white light.

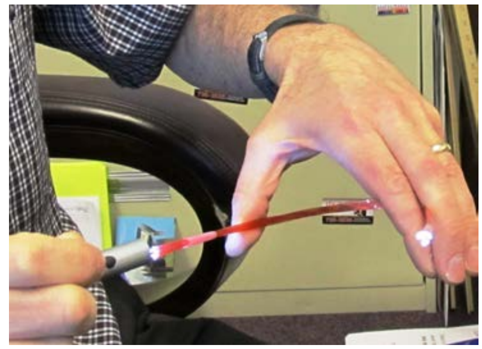
Notes:

- Diffraction is the spreading of light that occurs as the light encounters an obstacle. Refraction, on the other hand, is the bending of light rays that occurs as the properties of the medium of travel undergo changes (such as light moving from water into air).

Item	*Source*	*Item Number*	*Cost*
Diffraction Grating Slide	Rainbowsymphony.com	01602	0.40

Light through fiber optic cable

Students shine a light into one end of a length of fiber optic cable and observe the other end of the cable.



Setup:

- The students will shine a flashlight into one end of the cable and watch the other end of the cable.
- Sharp kinks or creases in the cable will break the thin glass fiber on the inside. Students must handle it with a bit of care.

Notes:

- The big realization here is that light isn't obligated to travel in a straight line when traveling through a medium such as glass.
- Some students will know that fiber optic cable is used to transmit telephone and cable TV signals over long distances.
- Beware of using un-jacketed fiber optic strands that can break/splinter

Item	*Source*	*Item Number*	*Cost*
24" fiber cable	Surplus Shed	M4076	5

Sound through a tin can telephone

Two students send sound messages through a wire that connects a pair of tin can telephones

Setup:

- After years of research we haven't yet perfected our tin can telephone. We use copper magnet wire but teachers tell us that string works just as well.

Notes:

- This device permits the transmission of information by sending sound waves through metal. This is a key station for the information transfer performance expectation.

Item	*Source*	*Item Number*	*Cost*
Two metal cans	Safeway	Tomatoes	2.00 x 2
String	Safeway	String	3.29

Vibrations of light at frequencies of sound

Students observe the reflection of a laser beam from a vibrating surface. They notice that both the frequency and the volume of the sound that makes the vibrations affect the pattern of reflected light.

Setup:

- Find a length large diameter pipe. We use 8" white PVC irrigation pipe. Cut the neck from a 24" balloon and stretch the balloon over one end of the tube. Tape the balloon to the tube (that's yellow duct tape you see in the photo).
- Tape a small piece of a flat mirror to the center of the balloon membrane.
- Point the light from an eye-safe laser pointer at the mirror. Shine the reflected beam on a large white surface like a marker board or poster paper
- Place a speaker in the other end of the tube, facing the balloon membrane. We recommend a speaker system with a subwoofer for good bass fidelity
- Connect the speaker to a signal generator or a laptop running the Visual Analyzer software with the software in "wave" mode.
- Low frequencies work best. Change the frequencies of the sound waves coming out of the speaker and look for the frequencies that give the best response. You'll see this by watching the pattern of reflected laser light.
- Once you find a good frequency, change the volume of the sound coming out of the speaker and watch the response of the reflected laser beam.

Notes:

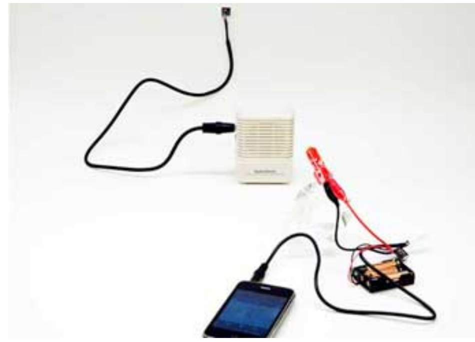
This station involves a somewhat complex and fussy setup, but the payoff is very good. Users are captivated by the patterns formed by the reflected beam at the resonant frequencies of the balloon skin.

Feel free to use narrower pipe; a full length of 8" diameter pipe is quite expensive ($114). You might be able to find a scrap piece of 8" at an industrial supply.

Item	*Source*	*Item Number*	*Cost*
8" Irrigation pipe	Lowe's	431148	114
PC Speakers	Quill.com	901-901578	12
24" balloon (5 pk)	Ziggos.com	Q1-4891	4.26

Transferring sound onto light

Students observe that the signal from a MP3 player can be converted to light and transmitted to speakers. Students observe the result when the light beam becomes blocked.



Setup:

- Some assembly required! You'll need to assemble the SpectraSound kit, an operation that's not terribly difficult but requires some wiring and some modification of the kit's laser pointer.
- You'll use the MP3 player to play some music. The MP3 signal will go onto the laser light, onto a light sensor and into the speakers. Students can interrupt the laser beam and turn off the music.

Notes:

If you can make it through the assembly process successfully, this is a wonderful setup to allow students to see the transfer of sound information on a beam of light.

Item	*Source*	*Item Number*	*Cost*
SpectraSound kit	http://store.aps.org	OR-SPECTRA	20
MP3 player	Best Buy	5616488	31
PC Speakers	Quill.com	901-901578	12

Master Materials List *Shipping costs not included*

Activity	Item	Source	Item Number	Cost
Slinky	Slinky	ToysRus	Slinky	5.00
Waves/Rope	20’ 5/8” nylon rope	Lowe’s	349190	13.60
Rain Gutter	10’ 4.5” plastic gutter	Lowe’s	12066	6.47
	Two 4.5” gutter caps	Lowe’s	12068	$2.97 x 2
	Small corks (size #4)	Amazon.com	Corks	8.99
Ripple Tank or Ripple Pan	Ripple tank kit	Carolina	754180	350
	Ripple tank light	Carolina	754185	56
	Small corks (size #4)	Amazon.com	Corks	8.99
	OR . . .			
	16” x 24” x 2” cake pan	Amazon.com	Parrish	37.21
Waves/Pencils	Wave machine	ShopAnatomical.com	3B-U8431805	151
	OR . . .			
	60 pencils	Staples	476919	8.45
	1” masking tape	Staples	468413	8.99
Rulers	Plastic rulers	Staples	382725	1.49 ea
Sound/Computer	Windows PC	School district or other	Excess	Free?
	Visual Analyzer	www.sillanumsoft.org	Choose version	Free
	PC microphone	OfficeSupply.com	IGRME92884	10.25
	Tuning fork set	Flinn Scientific	AP6982	64
Tuning fork pair	Symp. tuning forks	Flinn Scientific	AP5724	122
Flat mirror	Large flat mirror	Lowe’s	471106	15
	Colored electric tape	Lowe’s	291607	5.18
Curved mirror	Concave cosmetic mirror	Walmart	0030997104627	6
	Colored electric tape	Lowe’s	291607	5.18
Curved lenses	Jumbo mag glass	ToyStore-USA.com	LER-2775	6
	Large concave lens	Surplus Shed	L11175	8

Fiber optic cable	24” fiber cable	Surplus Shed	M4076	5
	LED flashlight	Lowe’s	494829	3
Tin can phone	Two metal cans	Safeway	Tomatoes	2.00 x 2
	String	Safeway	String	3.29
Sound/light	SpectraSound kit	http://store.aps.org	OR-SPECTRA	20
	MP3 player	Best Buy	5616488	31
	PC Speakers	Quill.com	901-901578	12

Student Handout

Waves on a Slinky

1. Lay the Slinky across a table or on the floor. Do the experiment with a partner so that each partner can hold an end of the Slinky. One partner should hold his or her end still. The other partner should move his or her end back and forth (sideways) slowly. Watch the waves that appear on the Slinky. Now move the end back and forth quickly. How does the wave pattern change when you move the end quickly? Draw the two Slinky patterns in the space below.

2. Now one partner should push the end of the Slinky in and out rather than shake it sideways. How is this wave pattern different from the first pattern? Draw a diagram to help your explanation

3. The waves you made in (1) are **transverse** waves and the waves you made in (2) are **compression** waves. Look up the definitions of transverse and compression if you need to. Why do these terms make sense for the types of waves you produced in (1) and (2)?

4. **Frequency** is the rate at which you shake or push the end of the Slinky. **Wavelength** is the distance between two waves on the Slinky. What does this experiment teach you about the relationship between frequency and wavelength?

5. What **energy** source created the waves on the Slinky?

Waves on a Rope

1. Do the experiment with a partner so that each partner can hold an end of the rope. One partner should hold his or her end still. The other partner should move his or her end back and forth slowly. Watch the waves that you make. Now one partner should move the end back and forth very quickly. How does the wave pattern change when you move the end quickly? Draw the two wave patterns in the space below.

2. **Frequency** is the rate that you shake the end of the rope. **Wavelength** is the distance between two waves on the rope. When you increase the frequency by moving your hand faster, how does the wavelength change?

3. How can you make the waves on the rope taller?

4. The height of the waves on the rope is related to **amplitude**. How do you need to move the end of the rope to make waves that have a short **wavelength** and large amplitude?

5. What’s the **energy** source that makes the waves on the rope?

Student Handout

Waves in a Rain Gutter

Push down on the water at the end of the gutter to make a single wave. Just make **one** wave, no more.

1. What happens to the wave when it reaches the end of the tank?

Now make one wave again. When the wave reaches the end of the gutter, make a second wave and watch the two waves collide

2. What happens when two waves collide with one another?

Place a couple of corks in the water. Now make three or four waves quickly. Watch the waves pass by the corks.

3. What happens to a cork when a wave goes by?

4. What does the cork experiment teach us about the way that waves move?

Make high-**frequency** waves by moving the pusher up and down four times quickly.

5. How much space is between the waves as they move? Draw a diagram. Is the **wavelength** in this experiment long or short?

Make low-**frequency** waves by moving the pusher up and down four times slowly.

6. How much space is between the waves this time? Draw a diagram. Is the wavelength in this experiment long or short?

Student Handout

Waves in a Ripple Tank

Make circular waves in the water by using the round ball on the end of the vibrating rod.

1. Draw a diagram of the pattern of circular waves.

Now make straight waves in the water by using the wood bar at the end of the rod.

2. Draw a diagram of the pattern of straight waves.

Change the speed of the motor slightly. Put a cork on the water and watch the cork as the waves go by

3. How does the straight wave pattern change when the motor speed changes?

4. What energy source creates the waves on the water?

5. When you see a wave moving through the water, is the water moving along with the wave? (Hint – watch the cork as the waves go by).

Put the angled board in the water on the far side of the pan. Make the board sink. Now send straight waves at the angled part of the board.

6. What happens to the waves when they reach the angled board?

Student Handout

Waves in a Cake Pan

Let the water become very still. Squeeze a single drop of water into the center of the pan.

1. Draw the wave pattern that you see when the drop hits the surface. Use arrows to show the directions of the waves.

Now use the long piece of wood. Use it to push down on the water at one end of the pan to make a wave that goes across the pan.

2. Draw the wave pattern that you see when you move the piece of wood up and down. Use arrows to show the direction of the waves.

Put a cork on the water. Move the wood bar up and down *slowly* to make low-**frequency** waves. Now move the wood bar up and down *quickly* to make high-**frequency** waves.

3. How does the wave pattern change when you speed up your movement of the wood bar?

4. What **energy** source creates the waves on the water?

5. When you see a wave moving through the water, is the water moving along with the wave? (Hint – watch the cork).

Put the angled board in the water on the far side of the pan. Make the board sink. Now send straight waves at the angled part of the board.

6. What happens to the waves when they reach the angled board?

Student Handout

Waves on Pencils

With one hand push down one side of the pencils at one end of the model and then remove your hand quickly. You should see a twisty wave move down the pencils.

1. What happens to a pencil wave when it reaches the end? What's the science vocabulary word that describes this process? (Hint – it's the word you use when you look in a mirror).

2. What do you need to do to make tall waves (large **amplitude**) at this station?

3. What do you need to do to make long waves (long **wavelength**) at this station?

4. Do the pencil waves bounce back and forth forever? What do you think causes the waves to stop?

5. Make waves on the machine and watch just one pencil. How does one pencil move?

Student Handout

PhET Wave Applet (Named *Wave Interference*)

http://phet.colorado.edu/en/simulation/wave-interference

Begin by selecting the "Water" tab for the simulation. Watch the water droplets fall from the faucet into the pool. Now move the **Frequency** slider with the mouse.

1. What change do you observe when you change the **frequency** slider?

2. Based on this example, what do you think **frequency** means?

Now move the **Amplitude** slider.

3. What changes do you observe?

Click the "Show Graph" button below the water pool. Watch the graph and the pool as you move the **amplitude** slider.

4. Based on this example, what do you think **amplitude** means?

On the right-side panel, move the "Rotate View" slider from "Top" to "Side." Watch the side view of the water and the graph as you move the **amplitude** and **frequency** sliders.

5. **Wavelength** means the distance between two crests (high points) or troughs (low points) on two side-by-side waves. When you increase the **frequency** of the waves, what happens to the **wavelength** of the waves?

6. When you decrease the **frequency** of the waves, what happens to the **wavelength** of the waves?

Now spend a few minutes experimenting with the simulator in whatever ways you would like.

Student Handout

Vibrating Ruler

Place 4 inches of the ruler over the edge of the desk. Hold down the other end of the ruler tightly, right at the edge of the desk. Now *lightly* pluck the end of the ruler that's hanging over the desk.

1. What do you hear when you pluck?

Now pluck harder.

2. How does the sound change when you pluck harder?

3. How does the motion of the ruler change when you pluck harder?

4. The amount that the ruler vibrates back and forth is called **amplitude**. This experiment shows that more amplitude produces a _______________ sound.

Now shorten the amount of the ruler that's hanging over. Try 3 inches and pluck. Then try two inches and pluck.

5. How does the motion of the ruler change when you shorten the length that you pluck?

6. How does the sound of the ruler change when you shorten the length that you pluck?

7. The number of times in a second that the ruler vibrates is called **frequency**. This experiment shows that a higher frequency produces a ______________ sound.

Student Handout

Vibrating Speaker

A. Turn on the amplifier

B. Turn on the signal generator

C. Turn the “fine adjust” knob on the signal generator

D. Observe the system – look, listen, touch (lightly)

Questions

1. What do you feel with your fingers at this station once you turn on the equipment?

2. When you change the fine adjust knob on the signal generator, you’re changing the **frequency** of the waves that the generator makes. How does the speaker’s behavior change when you change the **frequency**?

3. If you turn the frequency knob low enough, you’ll stop hearing sound from the speaker. Has the speaker stopped vibrating? What does this result tell you about the way that your ear works?

4. Fill in the blank: When we hear sound, we know that something is ____________________.

Student Handout

Measuring Sound Waves on a Computer

Hold a tuning fork by the very bottom. Hit the tuning fork with the rubber end of the mallet or tap the fork on your shoe. Please don't tap the fork on a hard surface; this will wear out the forks.

Try a short tuning fork. Hold the tuning fork close to your ear after you tap it.

1. What do you hear after you tap the fork and hold it close to your ear?

Now try a long tuning form.

2. How is the sound from the long fork different than the short fork?

Find the short fork again. This time tap it and hold the fork close to the microphone. Watch the computer screen.

3. Draw a diagram of the pattern that you see on the computer screen.

Now find the long fork again. Tap it and hold it close to the microphone. Watch the screen.

4. Is the pattern from the long fork that same as the pattern from the short fork?

5. Draw a diagram of the pattern that you see on the computer screen for the long fork.

6. What does this experiment teach us about sound waves?

Student Handout

Sound waves – vibrations of air

Turn on the blow dryer and pull the trigger to use non-heated air. Blow the stream of air across the tops of the bottles. Observe.

1. What difference do you notice in the sound as you move the air from one bottle to another?

2. What appears to cause the bottles to make sounds of different pitch?

3. The sound comes from the air that's vibrating above the surface of the water in the bottles. The air from the hair dry makes the air inside the bottle vibrate. What do you conclude about the relationship between the length of the vibrating air in the bottle and the pitch of the sound?

4. Have you ever seen anything else that behaves like these bottles – something that's long and makes sound of a lower pitch, and something that's short and makes sound of a higher pitch?

Student Handout

A Pair of Tuning Forks

At this station you can only use the mallet on the tuning fork. Don't tap the forks with anything else.

Move one tuning fork and its box very far from the other one. Now tap one of the forks and hold the open end of the box close to your ear.

1. What do you hear after you tap the fork?

Now tap the fork again and this time touch it with your finger.

2. What do you feel when you touch the fork with your finger?

3. What happens to the sound when you touch the fork with your finger?

Now move the two forks together so that the open ends of the boxes face each other but don't touch each other. Tap one of the tuning forks.

4. Now touch the other tuning fork – the one that you didn't tap. What do you notice?

Pick up the boxes. Hold both boxes in your hands so that the open ends face each other but don't touch. Ask your partner to tap one of the tuning forks while the boxes face each other. Now move the other box so that you're listening to the open end of the box.

5. What do you notice? When you listen to the box of the fork that you didn't tap?

6. List three things that this experiment teaches us about sound.

    a.

    b.

    c.

Student Handout

Sound waves through metal

Line up a row of ball bearings along the flat part of the track. Make sure that the bearings are sitting still and touching each other. Now launch another ball bearing from the top of the track so that the bearing rolls down and collides with the bearing at the end of the row. Observe what happens.

1. Write your observation. Draw and label a diagram that illustrates your observation.

2. How much time elapsed between the instant that the rolling ball struck one of the row of balls and the ball at the opposite end jumped away?

3. How is it possible that the far ball was able to move away from the end of the row so quickly?

4. What does this station teach us about the speed of sound waves that go through metal?

Student Handout

PHET Sound applet

Run the PhET sound wave simulation from phet.colorado.edu/en/simulation/sound.

1. Change the **amplitude** setting on the screen controls. How would you describe the change that you see in the simulated waves when you change the amplitude? What change do you think you would notice if you changed the amplitude of real sound waves?

2. Change the **frequency** of the sound waves using the screen controls. What change do you observe in the simulation when you change the frequency? What change do you think you would observe in real life when you change the frequency of sound waves?

3. What's an actual experiment that you've done at these stations that teaches you the same things as this computer simulation? (You'll need to answer this question later if this is your first station).

4. What's the relationship between the **frequency** of sound waves and the **wavelength** of sound waves?

Student Handout

Reflections from a Flat Mirror

Stand straight in front of the mirror on the yellow tape. Look at the mirror.

1. What do you see?

Find a partner. Stand on the yellow mark. Ask your partner to stand on a red mark. Both of you should look at the mirror.

2. Can you see each other in the mirror?

Now stand right next to your partner near your partner's red mark. The two of you should be shoulder to shoulder.

3. Can you see each other in the mirror?

Leave your partner on the red mark. Move to the red mark that's on the opposite side of the mirror.

4. Can you see your partner in the mirror now?

Both you and your partner should stand on the green marks that are farther from the mirror. You should be on opposite sides of the mirror.

5. Can you see each other in the mirror now?

One of you should stay on a green mark and one of you should move up to a red mark. You should be on opposite sides of the mirror.

6. Can you see each other in the mirror now?

7. What does this experiment teach us about the way that light **reflects** from a mirror?

Student Handout

Reflections from a Curved Mirror

Stand close to the curved mirror on the black tape mark and look at your **reflection**.

1. What do you see? Does your **reflection** look normal?

Now back away from the mirror and stand on the red tape mark. Find the **reflection** of your face in the mirror (this might be hard – be patient and make it work).

2. Now what do you see? Does your **reflection** look normal?

3. What is your idea about why the **reflection** looks so different at different distances?

4. Try to draw a diagram of the light rays **reflecting** from the mirror that helps you understand why your image at a distance turns upside down.

Student Handout

Light through Curved Lenses

One at a time, carefully hold the lenses close to your eye. Look through them at your hand when you hold your hand close to the lens on the other side from your eye.

1. Does your hand look the same through both lenses? Write a description of what you see

Now hold the lenses far from your eye. Stretch out your arm all the way and hold the lens at the end of your outstretched arm. Look trough the lenses at something that's on the other side of the room, or outside through the window.

2. Do you see the same thing through both of the lenses? Write a description of what you see.

Carefully run your fingers across the lenses.

3. What do you notice about the curvature of the lenses?

4. How does the curvature relate to the type of image you see through the lens ?

5. Look up a definition of **refraction**. What does this station teach you about **refraction**?

Student Handout

Light through prisms

Hold a prism by both ends so that the prisms sites horizontally in front of your eyes. Look through the prism. Roll the prism around as you look through.

1. Describe what you see when you look through the prism.

2. Does there appear to be a connection between the way you hold the prism and what you see when you look through?

3. Is it possible to see rainbows when you look through the prism? What's necessary in order for rainbows to be visible?

4. In general terms, what does the prism appear to do to light that passes through it?

Student Handout

Light through a diffraction grating

Hold up a piece of **diffraction** grating and look at a fluorescent light in the room.

1. Draw a diagram of what you see when you look through the grating at a light.

Don’t look right at the Sun through the grating, but look at a window or go outside on a sunny day and look at the sky near the Sun.

2. Do you notice a difference between the color patterns (spectrum) that you see from the room lights compared to the spectrum from the Sun?

3. What’s the order of colors that you see in the spectrum when you look at a white light through a **diffraction** grating?

4. What’s your idea about how the **diffraction** grating works?

Student Handout

Light through Fiber Optic Cable

At this station you must handle the cable gently. If you bend it sharply or fold it, the glass in the cable will break.

Hold one end of the cable and ask your partner to hold the other end. Gently straighten the cable. Shine a flashlight in one end of the cable. Ask you partner to look at the other end.

1. What does your partner see at the other end?

Now ask you partner to stand next to you, facing the same way, so that the two of you are holding the cable in horseshoe shape. Shine your light in one end of the cable.

2. What do you see at the other end?

Now gently coil the cable into a circle (not a very tight circle). Repeat the test with the flashlight.

3. What do you see at the other end of the cable?

4. Light usually goes in a straight direction unless we do something to the light. One way to change the direction of light is by using a m _ _ _ _ _.

5. The glass inside the cable acts like many, many __________, causing the light to change direction by many **reflections** and follow the curve of the cable.

Student Handout

Sound through Tin Can Telephone

Find a partner. Each of you should hold a can at the open end. Stretch the string so that it's tight (**but don't break the string**). Take turns talking and listening in the cans.

1. Can you understand each other? How well does the sound carry through the string?

One of you should pinch the string. Now repeat the talking and listening experiment.

2. What happens when you pinch the string?

3. What's your idea about why pinching the string changes the way the phone work?

4. In what way is this system like a real phone? How is it different from a real phone?

5. Pretend for a moment that you could make a string telephone with a 500-foot string and that the phone still would work ((you could hear each other). What would you notice that's funny about the way the phone transmits the sound? (Hint – think about the time difference when you see a lightning bolt and hear the thunder that goes with the lightning.)

Student Handout

Vibrations of light at frequencies of sound

Study the apparatus at this station so that you understand how it's put together. Find the balloon, the mirror, the laser, the speakers and the signal generator

Operate the activity by running the volume control on the speakers. Watch the reflected laser light on the white screen as you turn the volume up and down.

1. Draw a rough diagram of the setup at this station. Label the diagram.

2. Draw some of the patterns you see on the white screen as you change the speaker volume.

3. What's your idea about the patterns? What do you think is causing the patterns?

4. Can you think of other things you've seen that act like the balloon in this experiment – surfaces that vibrate when sounds waves hit them?

Student Handout

Transferring Sound onto Light

Please handle the equipment carefully at this station!

Turn on the MP3 player. Turn on the speakers. Point the laser beam at the light sensor.

1. What observation do you make?

Put a piece of paper in front of the laser beam.

2. What observation do you make?

Move the paper in and out of the beam very rapidly.

3. What observation do you make?

4. What's going on at this station? How do you think it works?

5. How could a system like this be useful to people?

Conceptual Background for Students

Some things happen just once and they never happen again. A person might win the lottery, for example, but most likely only. Most things, however, happen repeatedly according to some type of cycle. The U.S. Census occurs once per decade. School starts once per year. Families make a house or apartment payment once per month. We sleep for seven or eight hours each 24-hour day. Events that happen according to a pattern are called **periodic**. One of the most basic questions we can ask is “How much time is needed for a pattern to go through its cycle once?” This time, the length of time for one cycle of a pattern, is named **period.** What are the periods of the following events?

- A clock cycle (12 hours)
- The bus ride to school (One day – the time between bus rides to school)
- Your birthday (one year)
- The Moon’s orbit around the Earth (one month)
- The Earth’s Orbit around the Sun (one year)
- Pluto’s orbit around the Sun (250 years)

When cyclic events happen very quickly, people usually don’t talk about the period of the process because the period becomes a very small number, perhaps a very tiny fraction of a second. Instead we take the reciprocal of the period to convert the period to the frequency, which is the number of times per second that the event occurs. We use the unit Hertz for frequency, Hz. One Hz represents one cycle per second. 100 Hz represents 100 cycles per second. Here are some frequencies of common periodic processes (vibrations) that happen quickly.

- Alternating electric current that we use in the U.S.: 60 Hz
- Sound waves: 20 Hz to 20,000 Hz
- Radio waves: Thousands of Hz to millions of Hz
- Visible light waves: Trillions of Hz

Vibrations can transfer energy to the environment in the form of **waves**. We call the environment that carries the waves the **medium**. When an earthquake occurs, vibrations at the epicenter move into the surrounding material (the medium) as seismic waves. When the wind blows over the ocean, vibrations move into the surrounding water (the medium) as water waves. When our vocal cords vibrate, these vibrations move into the surrounding air (the medium) as sound waves. Waves possess periods and frequencies, but they also possess a **wavelength –** the length between identical parts of two neighboring waves.. The **speed** at which a wave moves through a medium equals the product of the frequency and wavelength of the wave.

Waves fall into two main categories. **Transverse** waves vibrate back and forth in a direction that’s perpendicular to the direction of their forward motion. **Longitudinal** or **compression** waves vibrate back and forth in a direction that’s the same as the direction of their forward motion. We use **amplitude** to characterize the extent of the vibration.

All waves undergo certain behaviors such as **reflection** (bouncing off an obstacle) and **refraction** (changing their direction because of a change in some property of the medium).

Waves can **transmit information** from one place to another. The frequencies of sound waves give rise to the properties of pitch and tone and allow us to transmit information as sound. The frequencies of visible light give rise to color, another mechanism of information transfer.

These days most information transfer happens digitally. When we speak into our phones, our sound waves of are turned into strings of digital “bits” – strings of zeroes and ones that contain the original sound information. Computers don’t understand all numbers; they only understand bits made of ones and zeroes. Digital technology gives engineers a more efficient information transfer method that allows for computerized control.

Sample Answers for the Student Handouts

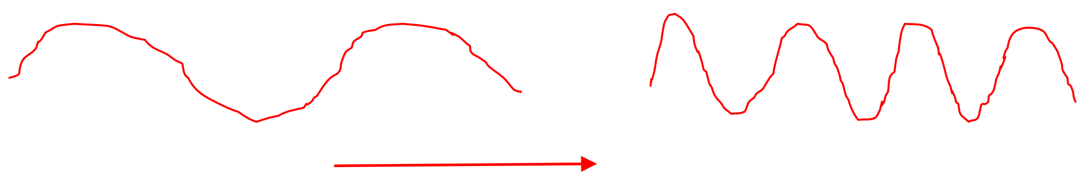
The wave stations should encourage both teacher and student to engage in inquiry-based explorations while building an understanding of the science of waves. The process of science involves struggle; science teaching usually improves when teachers experience the struggle along with the students. Knowing how to struggle is vitally important in an operation such as LIGO where scientists and engineers don't possess an answer key – they're building knowledge for the first time.

Bearing the above in mind, the developers provide the following sheets that contain typical student responses to the station questions. These responses shouldn't be considered "correct" answers. These responses represent what many students will write if they observe what the stations intend. These filled-in sheets might be use when teachers are wondering if students are manipulating the activities in the intended way.

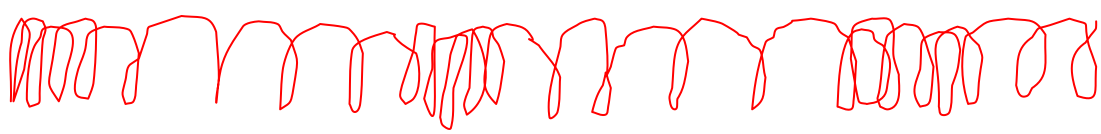
Student Handout

Waves on a Slinky

1. Lay the Slinky across a table or on the floor. Do the experiment with a partner so that each partner can hold an end of the Slinky. One partner should hold his or her end still. The other partner should move his or her end back and forth (sideways) slowly. Watch the waves that appear on the Slinky. Now move the end back and forth quickly. How does the wave pattern change when you move the end quickly? Draw the two Slinky patterns in the space below.



2. Now one partner should push the end of the Slinky in and out rather than shake it sideways. How is this wave pattern different from the first pattern? Draw a diagram to help your explanation



3. The waves you made in (1) are **transverse** waves and the waves you made in (2) are **compression** waves. Look up the definitions of transverse and compression if you need to. Why do these terms make sense for the types of waves you produced in (1) and (2)?

   We make compression waves by compressing the spring. We make transverse waves by swinging the spring sideways. Transverse basically means sideways.

4. **Frequency** is the rate at which you shake or push the end of the Slinky. **Wavelength** is the distance between two waves on the Slinky. What does this experiment teach you about the relationship between frequency and wavelength?

   When the frequency becomes higher, the wavelength becomes shorter.

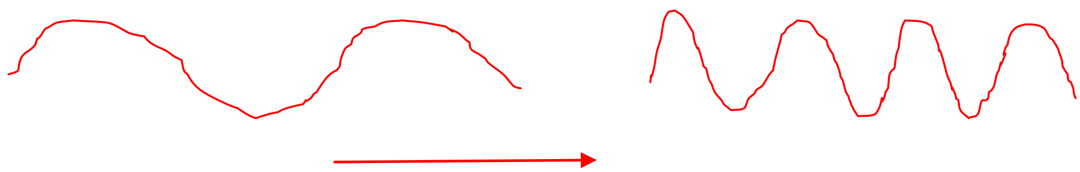
5. What **energy** source created the waves on the Slinky?

   Energy from the movement of my hand.

Student Handout

Waves on a Rope

1. Do the experiment with a partner so that each partner can hold an end of the rope. One partner should hold his or her end still. The other partner should move his or her end back and forth slowly. Watch the waves that you make. Now one partner should move the end back and forth very quickly. How does the wave pattern change when you move the end quickly? Draw the two wave patterns in the space below.



2. **Frequency** is the rate that you shake the end of the rope. **Wavelength** is the distance between two waves on the rope. When you increase the frequency by moving your hand faster, how does the wavelength change?

   When the frequency increases, the wavelength decreases.

3. How can you make the waves on the rope taller?

   Move your hand through a greater distance when you're shaking the end of the rope.

4. The height of the waves on the rope is related to **amplitude**. How do you need to move the end of the rope to make waves that have a short **wavelength** and large **amplitude**?

   Move your hand through a large distance and move it as quickly as you can.

5. What's the **energy** source that makes the waves on the rope?

   The energy from the movement of my hand.

Student Handout

Waves in a Rain Gutter

Push down on the water at the end of the gutter to make a single wave. Just make **one** wave, no more.

1. What happens to the wave when it reaches the end of the tank?
   The wave hits the end of the gutter and bounces back; it comes back in the reverse direction

Now make one wave again. When the wave reaches the end of the gutter, make a second wave and watch the two waves collide

2. What happens when two waves collide with one another?
   It's hard to tell. The waves seem to pass right through each other and keep going.

Place a couple of corks in the water. Now make three or four waves quickly. Watch the waves pass by the corks.

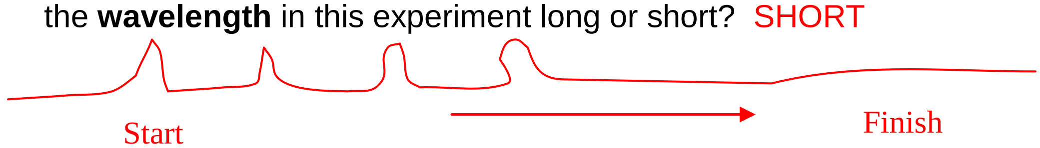
3. What happens to a cork when a wave goes by?

The cork moves sideways a little bit but not much. It mainly bobs up and down.

4. What does the cork experiment teach us about the way that waves move?
   When waves move, they don't carry material with them.

Make **high-frequency** waves by moving the pusher up and down four times quickly.

5. How much space is between the waves as they move? Draw a diagram. Is the **wavelength** in this experiment long or short? SHORT



Make **low-frequency** waves by moving the pusher up and down four times slowly.

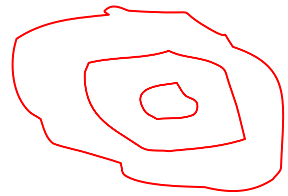
6. How much space is between the waves this time? Draw a diagram. Is the wavelength in this experiment long or short? LONG

Student Handout

Waves in a Ripple Tank

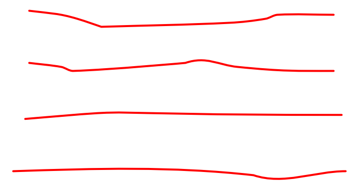
Make circular waves in the water by using the round ball on the end of the vibrating rod.

1. Draw a diagram of the pattern of circular waves.



Now make straight waves in the water by using the wood bar at the end of the rod.

2. Draw a diagram of the pattern of straight waves.



Change the speed of the motor slightly. Put a cork on the water and watch the cork as the waves go by

3. How does the straight wave pattern change when the motor speed changes?

   If the motor goes faster, the waves get closer.

4. What energy source creates the waves on the water?

   The energy from the motor that makes the wood bar move

5. When you see a wave moving through the water, is the water moving along with the wave? (Hint – watch the cork as the waves go by).

   The cork doesn't move with the wave, which means that the water doesn't move with the wave. The wave goes through the water.

Put the angled board in the water on the far side of the pan. Make the board sink. Now send straight waves at the angled part of the board.

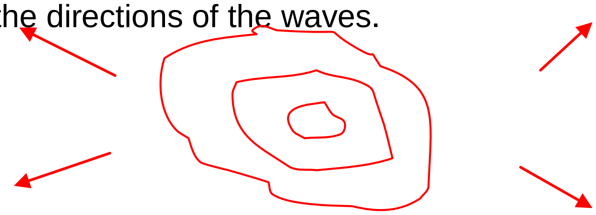
6. What happens to the waves when they reach the angled board?

   The waves change direction. They bend to follow the angle of the board

Waves in a Cake Pan

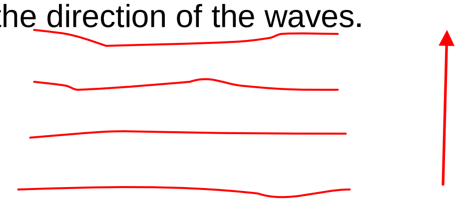
Let the water become very still. Squeeze a single drop of water into the center of the pan.

1. Draw the wave pattern that you see when the drop hits the surface. Use arrows to show the directions of the waves.



Now use the long piece of wood. Use it to push down on the water at one end of the pan to make a wave that goes across the pan.

2. Draw the wave pattern that you see when you move the piece of wood up and down. Use arrows to show the direction of the waves.



Put a cork on the water. Move the wood bar up and down *slowly* to make **low-frequency** waves. Now move the wood bar up and down *quickly* to make **high-frequency** waves.

3. How does the wave pattern change when you speed up your movement of the wood bar?
   The waves are closer together. The spacing between them is less.

4. What **energy** source creates the waves on the water?
   The energy from the movement of my hand.

5. When you see a wave moving through the water, is the water moving along with the wave? (Hint – watch the cork).
   The wave passes by the cork. The cork isn't carried by the wave.

Put the angled board in the water on the far side of the pan. Make the board sink. Now send straight waves at the angled part of the board.

6. What happens to the waves when they reach the angled board?
   The waves change direction. They bend to follow the angle of the board.

Student Handout

Waves on Pencils

With one hand push down one side of the pencils at one end of the model and then remove your hand quickly. You should see a twisty wave move down the pencils.

1. What happens to a pencil wave when it reaches the end? What's the science vocabulary word that describes this process? (Hint – it's the word you use when you look in a mirror).

   The wave bounces back -- reflection

2. What do you need to do to make tall waves (large **amplitude**) at this station?

   Move the pencils more when you start the waves. Push them down more.

3. What do you need to do to make long waves (long **wavelength**) at this station?

   Wobble the pencils more slowly.

4. Do the pencil waves bounce back and forth forever? What do you think causes the waves to stop?

   No, the pencil waves lose energy as they travel and become smaller. This is probably due to friction.

5. Make waves on the machine and watch just one pencil. How does one pencil move?

   One pencil just bobs up and down.

Student Handout

PhET Wave Applet (Named *Wave Interference*)

http://phet.colorado.edu/en/simulation/wave-interference

Begin by selecting the “Water” tab for the simulation. Watch the water droplets fall from the faucet into the pool. Now move the **Frequency** slider with the mouse.

1. What change do you observe when you change the **frequency** slider?
   The waves occur more frequently and they get closer together

2. Based on this example, what do you think **frequency** means?
   The number of waves that occur in a certain amount of time.

Now move the **Amplitude** slider.

3. What changes do you observe?
   The waves get bigger – taller.

Click the “Show Graph” button below the water pool. Watch the graph and the pool as you move the **amplitude** slider.

4. Based on this example, what do you think **amplitude** means?
   The height of the waves – how tall they are.

On the right-side panel, move the “Rotate View” slider from “Top” to “Side.” Watch the side view of the water and the graph as you move the **amplitude** and **frequency** sliders.

5. **Wavelength** means the distance between two crests (high points) or troughs (low points) on two side-by-side waves. When you increase the **frequency** of the waves, what happens to the **wavelength** of the waves?
   A higher frequency gives a shorter wavelength

6. When you decrease the **frequency** of the waves, what happens to the **wavelength** of the waves?
   Lower frequency gives a longer wavelength

Now spend a few minutes experimenting with the simulator in whatever ways you would like.

Student Handout

Vibrating Ruler

Place 4 inches of the ruler over the edge of the desk. Hold down the other end of the ruler tightly, right at the edge of the desk. Now *lightly* pluck the end of the ruler that's hanging over the desk.

1. What do you hear when you pluck?

   A weird very low wobbly noise

Now pluck harder.

2. How does the sound change when you pluck harder?

   The sound becomes louder.

3. How does the motion of the ruler change when you pluck harder?

   The ruler makes a bigger vibration – it moves back and forth through a greater distance.

4. The amount that the ruler vibrates back and forth is called **amplitude**. This experiment shows that more amplitude produces a louder sound.

Now shorten the amount of the ruler that's hanging over. Try 3 inches and pluck. Then try two inches and pluck.

5. How does the motion of the ruler change when you shorten the length that you pluck?
   The ruler vibrates more quickly – higher frequency.

6. How does the sound of the ruler change when you shorten the length that you pluck?

   The pitch of the sound gets higher.

7. The number of times in a second that the ruler vibrates is called **frequency**. This experiment shows that a higher frequency produces a high-pitch sound.

Student Handout

Vibrating Speaker

A. Turn on the amplifier

B. Turn on the signal generator

C. Turn the “fine adjust” knob on the signal generator

D. Observe the system – look, listen, touch (lightly)

Questions

1. What do you feel with your fingers at this station once you turn on the equipment?

   The speaker vibrates

2. When you change the fine adjust knob on the signal generator, you’re changing the **frequency** of the waves that the generator makes. How does the speaker’s behavior change when you change the **frequency**?

   The speaker vibrates faster at higher frequencies and slower at lower frequencies

3. If you turn the frequency knob low enough, you’ll stop hearing sound from the speaker. Has the speaker stopped vibrating? What does this result tell you about the way that your ear works?

   No, the speaker still vibrates even though I can’t hear it. Apparently our ears can’t hear sounds when the pitch becomes too low.

4. Fill in the blank: When we hear sound, we know that something is vibrating.

Student Handout

Measuring Sound Waves on a Computer

Hold a tuning fork by the very bottom. Hit the tuning fork with the rubber end of the mallet or tap the fork on your shoe. Please don't tap the fork on a hard surface; this will wear out the forks.

Try a short tuning fork. Hold the tuning fork close to your ear after you tap it.

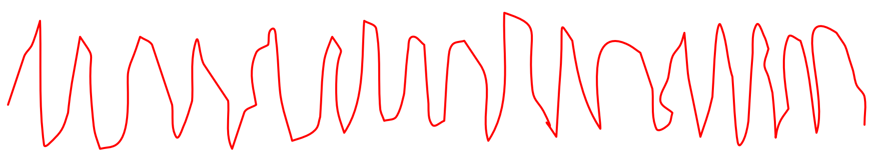
1. What do you hear after you tap the fork and hold it close to your ear?
   One sound – a single note

Now try a long tuning form.

2. How is the sound from the long fork different than the short fork?
   The long fork makes a sound with lower pitch

Find the short fork again. This time tap it and hold the fork close to the microphone. Watch the computer screen.

3. Draw a diagram of the pattern that you see on the computer screen.

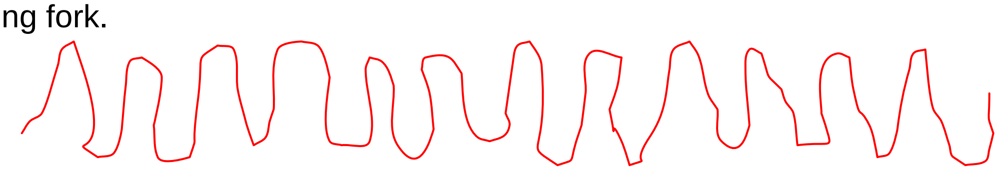


Now find the long fork again. Tap it and hold it close to the microphone. Watch the screen.

4. Is the pattern from the long fork that same as the pattern from the short fork?

   Yes, but the waves are more spread out

5. Draw a diagram of the pattern that you see on the computer screen for the long fork.



6. What does this experiment teach us about sound waves?
   Sound waves from high-pitch sounds have higher frequencies and sounds waves from low-pitch sounds have lower frequencies.

Student Handout

Sound waves – vibrations of air

Turn on the blow dryer and pull the trigger to use non-heated air. Blow the stream of air across the tops of the bottles. Observe.

1. What difference do you notice in the sound as you move the air from one bottle to another?

   The pitch of the sound changes

2. What appears to cause the bottles to make sounds of different pitch?

   The bottles contain different amounts of water

3. The sound comes from the air that's vibrating above the surface of the water in the bottles. The air from the hair dry makes the air inside the bottle vibrate. What do you conclude about the relationship between the length of the vibrating air in the bottle and the pitch of the sound?

   The longer the air column in the bottle, the lower the pitch of the sound

4. Have you ever seen anything else that behaves like these bottles – something that's long and makes sound of a lower pitch, and something that's short and makes sound of a higher pitch?

Tuning forks, musical instruments, pipe organ pipes

Student Handout

A Pair of Tuning Forks

At this station you can only use the mallet on the tuning fork. Don't tap the forks with anything else.

Move one tuning fork and its box very far from the other one. Now tap one of the forks and hold the open end of the box close to your ear.

1. What do you hear after you tap the fork?
   I can hear a sound – a note.

Now tap the fork again and this time touch it with your finger.

2. What do you feel when you touch the fork with your finger?
   I can feel the vibrations of the tuning fork.

3. What happens to the sound when you touch the fork with your finger?
   The sound stops.

Now move the two forks together so that the open ends of the boxes face each other but don't touch each other. Tap one of the tuning forks.

4. Now touch the other tuning fork – the one that you didn't tap. What do you notice?
   I can feel the second fork vibrate.

Pick up the boxes. Hold both boxes in your hands so that the open ends face each other but don't touch. Ask your partner to tap one of the tuning forks while the boxes face each other. Now move the other box so that you're listening to the open end of the box.

5. What do you notice? When you listen to the box of the fork that you didn't tap?
   The second box makes sound even though I didn't tap the second fork

6. List three things that this experiment teaches us about sound.

   a. Sound is made when things vibrate

   b. One vibrating thing can make something else vibrate without touching it

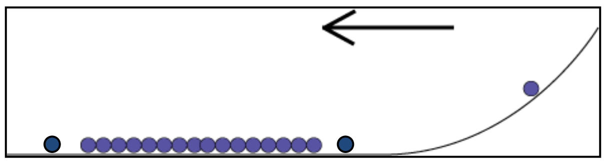
   c. Sound waves are vibrations that travel through the air

Student Handout

Sound waves through metal

Line up a row of ball bearings along the flat part of the track. Make sure that the bearings are sitting still and touching each other. Now launch another ball bearing from the top of the track so that the bearing rolls down and collides with the bearing at the end of the row. Observe what happens.

1. Write your observation. Draw and label a diagram that illustrates your observation.



As soon as the rolling ball hits the stationary ball on the end, the ball on the opposite end pops off

2. How much time elapsed between the instant that the rolling ball struck one of the row of balls and the ball at the opposite end jumped away?

Very little time elapsed. The opposite ball moved nearly at the same time that the rolling ball hit the end.

3. How is it possible that the far ball was able to move away from the end of the row so quickly?

A wave traveled quickly through the row of balls and transferred energy to the last ball

4. What does this station teach us about the speed of sound waves that go through metal?

Sound waves go through metal quickly.

Student Handout

PHET Sound applet

Run the PhET sound wave simulation from phet.colorado.edu/en/simulation/sound.

1. Change the **amplitude** setting on the screen controls. How would you describe the change that you see in the simulated waves when you change the amplitude? What change do you think you would notice if you changed the amplitude of real sound waves?

   The waves get bigger when the amplitude increases. Bigger amplitude for real sound waves corresponds to louder sound.

2. Change the **frequency** of the sound waves using the screen controls. What change do you observe in the simulation when you change the frequency? What change do you think you would observe in real life when you change the frequency of sound waves?

   The spacing between the waves changes when the frequency changes. Changes in frequency become changes in pitch for real sound waves.

3. What's an actual experiment that you've done at these stations that teaches you the same things as this computer simulation? (You'll need to answer this question later if this is your first station).

   The speaker with the drinking straws; the station with the tuning forks.

4. What's the relationship between the **frequency** of sound waves and the **wavelength** of sound waves?

   When we increase the frequency of sound waves, the wavelength gets shorter.

Student Handout

Reflections from a Flat Mirror

Stand straight in front of the mirror on the yellow tape. Look at the mirror.

1. What do you see?
   Myself

Find a partner. Stand on the yellow mark. Ask your partner to stand on a red mark. Both of you should look at the mirror.

2. Can you see each other in the mirror?

   No

Now stand right next to your partner near your partner's red mark. The two of you should be shoulder to shoulder.

3. Can you see each other in the mirror?
   No

Leave your partner on the red mark. Move to the red mark that's on the opposite side of the mirror.

4. Can you see your partner in the mirror now?
   Yes

Both you and your partner should stand on the green marks that are farther from the mirror. You should be on opposite sides of the mirror.

5. Can you see each other in the mirror now?
   Yes

One of you should stay on a green mark and one of you should move up to a red mark. You should be on opposite sides of the mirror.

6. Can you see each other in the mirror now?
   No

7. What does this experiment teach us about the way that light **reflects** from a mirror?
   Light reflects at an angle unless I'm straight in front. The light comes off the mirror at the same angle that it hits the mirror.

Student Handout

Reflections from a Curved Mirror

Stand close to the curved mirror on the black tape mark and look at your **reflection.**

1. What do you see? Does your **reflection** look normal?

   My reflection looks distorted. My nose is too big.

Now back away from the mirror and stand on the red tape mark. Find the **reflection** of your face in the mirror (this might be hard – be patient and make it work).

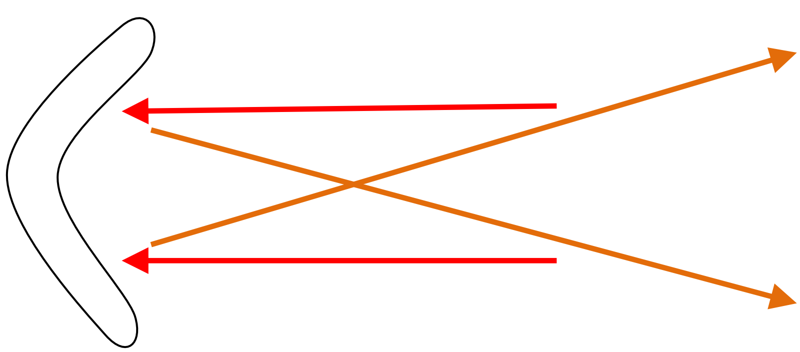
2. Now what do you see? Does your **reflection** look normal?

   I'm upside down!

3. What is your idea about why the **reflection** looks so different at different distances?

   Something happens to the light that causes the reflection to turn upside down at a distance.

4. Try to draw a diagram of the light rays **reflecting** from the mirror that helps you understand why your image at a distance turns upside down.



Student Handout

Light through Curved Lenses

One at a time, carefully hold the lenses close to your eye. Look through them at your hand when you hold your hand close to the lens on the other side from your eye.

1. Does your hand look the same through both lenses? Write a description of what you see

   One lens makes my hand appear bigger and the other lens makes my hand appear smaller

Now hold the lenses far from your eye. Stretch out your arm all the way and hold the lens at the end of your outstretched arm. Look trough the lenses at something that's on the other side of the room, or outside through the window.

2. Do you see the same thing through both of the lenses? Write a description of what you see.

   One lens turns things upside down. The other lens makes things smaller.

Carefully run your fingers across the lenses.

3. What do you notice about the curvature of the lenses?

   They're opposite. One curves outward, the other curves inward.

4. How does the curvature relate to the type of image you see through the lens ?

   The outward-curving lens makes things appear bigger (when close), the inward curving lens makes things appear smaller.

5. Look up a definition of **refraction**. What does this station teach you about **refraction**?
   The way that light refracts through a lens depends on the curvature of the lens.

Student Handout

Light through prisms

Hold a prism by both ends so that the prisms sites horizontally in front of your eyes. Look through the prism. Roll the prism around as you look through.

1. Describe what you see when you look through the prism.

   Objects are very distorted, or upside down, or missing.

2. Does there appear to be a connection between the way you hold the prism and what you see when you look through?

   It's hard to figure out. I see a mixture of right-side-up and distorted (curved), upside down, and reflections.

3. Is it possible to see rainbows when you look through the prism? What's necessary in order for rainbows to be visible?

   I can only see the rainbows by looking at lights that are far away, or by looking at the very bottom of the prism at lights that are closer. The angle must be just right.

4. In general terms, what does the prism appear to do to light that passes through it?

   The prism changes the direction of the light that passes through it. It bends the light, which causes distortions in the appearance of objects.

Student Handout

Light through a diffraction grating

Hold up a piece of **diffraction** grating and look at a fluorescent light in the room.

1. Draw a diagram of what you see when you look through the grating at a light.

   Rainbows

Don't look right at the Sun through the grating, but look at a window or go outside on a sunny day and look at the sky near the Sun.

2. Do you notice a difference between the color patterns (spectrum) that you see from the room lights compared to the spectrum from the Sun?

   The colors from the Sun's pattern merge together to make a continuous rainbow. The colors from the lights are the colors of the rainbow, but the colors are separated from one another – they don't merge together

3. What's the order of colors that you see in the spectrum when you look at a white light through a **diffraction** grating?

   Red, orange, yellow, green, blue, purple

4. What's your idea about how the **diffraction** grating works?

   Somehow the grating splits the white light into the colors of the rainbow. There's something in the plastic that causes this to happen.

Student Handout

Light through Fiber Optic Cable

At this station you must handle the cable gently. If you bend it sharply or fold it, the glass in the cable will break.

Hold one end of the cable and ask your partner to hold the other end. Gently straighten the cable. Shine a flashlight in one end of the cable. Ask you partner to look at the other end.

1. What does your partner see at the other end?
   Bright light from the flashlight is coming out of the other end of the cable.

Now ask you partner to stand next to you, facing the same way, so that the two of you are holding the cable in horseshoe shape. Shine your light in one end of the cable.

2. What do you see at the other end?

   Same thing – the light still comes out of the cable even though the cable is curved

Now gently coil the cable into a circle (not a very tight circle). Repeat the test with the flashlight.

3. What do you see at the other end of the cable?

   Same thing, even though the cable is in a circle.

4. Light usually goes in a straight direction unless we do something to the light. One way to change the direction of light is by using a mirror.

5. The glass inside the cable acts like many, many __mirrors____, causing the light to change direction by many **reflections** and follow the curve of the cable.

Student Handout

Sound through Tin Can Telephone

Find a partner. Each of you should hold a can at the open end. Stretch the string so that it's tight (**but don't break the string**). Take turns talking and listening in the cans.

1. Can you understand each other? How well does the sound carry through the string?
   We can barely understand each other. The string works, but not that great.

One of you should pinch the string. Now repeat the talking and listening experiment.

2. What happens when you pinch the string?

Now I can't really hear anything coming through the string.

3. What's your idea about why pinching the string changes the way the phone work?

When I pinch the string, the string can't vibrate. The sound is carried by the vibration.

4. In what way is this system like a real phone? How is it different from a real phone?

It's like a real phone because something else besides the air is carrying my voice. It's not like a real phone because real phones use electricity and fiber optics or cellular communications (microwaves).

5. Pretend for a moment that you could make a string telephone with a 500-foot string and that the phone still would work ((you could hear each other). What would you notice that's funny about the way the phone transmits the sound? (Hint – think about the time difference when you see a lightning bolt and hear the thunder that goes with the lightning.)

Time would be needed for the sound waves to travel through the string. The person on the receiving end would need to wait for the waves to arrive

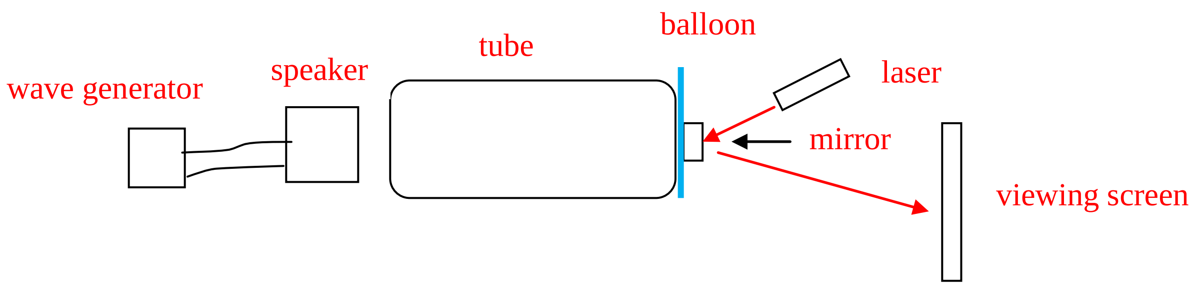
Student Handout

Vibrations of light at frequencies of sound

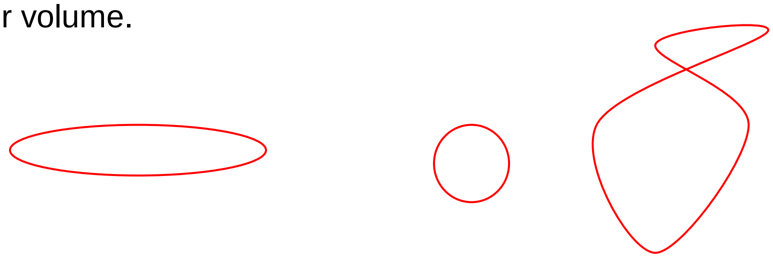
Study the apparatus at this station so that you understand how it's put together. Find the balloon, the mirror, the laser, the speakers and the signal generator

Operate the activity by running the volume control on the speakers. Watch the reflected laser light on the white screen as you turn the volume up and down.

1. Draw a rough diagram of the setup at this station. Label the diagram.



2. Draw some of the patterns you see on the white screen as you change the speaker volume.



3. What's your idea about the patterns? What do you think is causing the patterns?

The patterns show the way that the mirror and balloon are vibrating. The balloon vibrates differently at different frequencies.

4. Can you think of other things you've seen that act like the balloon in this experiment – surfaces that vibrate when sounds waves hit them?

The skin of a drum. Vocal chords. A wall.

Student Handout

Transferring Sound onto Light

Please handle the equipment carefully at this station!

Turn on the MP3 player. Turn on the speakers. Point the laser beam at the light sensor.

1. What observation do you make?

   I can hear the sound from the MP3 player coming out of the speaker.

Put a piece of paper in front of the laser beam.

2. What observation do you make?

   The paper blocks the laser beam and this blocks the sound

Move the paper in and out of the beam very rapidly.

3. What observation do you make?

   The music turns off and on as rapidly as I move the paper.

4. What's going on at this station? How do you think it works?

   The sound is carried on the light. When you block the light, you block the sound.

5. How could a system like this be useful to people?

   Light travels fast and can go long distances, and it doesn't cost much to make light. Light is good for communications.