Classroom Activities

Waves and Their Applications in Technologies for Information Transfer: 4th grade

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

Version 3
August 2015

This version of the fourth grade 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-T1400443/public

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

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LIGO is operated by the California Institute of Technology and the Massachusetts Institute of Technology and is funded by the National Science Foundation

Introduction

This packet contains classroom activities and materials designed to address the Disciplinary Core Ideas (DCI's) for standard 4-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.

A similar document exists for middle school and it contains a greater number of activities than this packet. A number of the additional activities 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.

The classroom context in which the fourth grade materials were tested involved a large percentage of students for whom English is not the first language, a circumstance that influenced the development of the student handouts for the activities.

Teachers will see that standard 4-PS4 presents two science and engineering practices and a crosscutting concept. Students inevitably will encounter these three elements as they work through the activities, but the packet materials deal explicitly only with the standard's DCI's.

There are three assessments included with this mini-unit. The first assessment is a design challenge that requires the students to design a method for information transfer and complete a written response; this assessment should be given at the end of the segment. The next assessment in the packet is a vocabulary matching worksheet; this will assess academic language knowledge and is a nice pairing to the Cognitive Content Dictionary and KWL activities. The final assessment created is a scientists' survey. This is an assessment that will be valuable to teachers for the creation of future lessons. Teachers should use their best practices and knowledge when creating a summative assessment to complement the assessments included in this packet.

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.

Contents

The NGSS Waves Standard at Grade Four

page 37, NGSS Standard 4-PS4, Next Generation Science Standards, Volume I. The National Academies Press, 2013

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

PERFORMANCE EXPECTATIONS

Students who demonstrate understanding can:

4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move. [*Clarification Statement*: Examples of models could include diagrams, analogies, and physical models using wire to illustrate the wavelength and amplitude of waves.] [*Assessment Boundary*: Assessment does not include interference effects, electromagnetic waves, non-periodic waves, or quantitative models of amplitude and wavelength.]

4-PS4-2. Develop a model to describe that light reflecting from objects and entering the eyes allows objects to be seen. [*Assessment Boundary*: Assessment does not include knowledge of specific colors reflected and seen, the cellular mechanisms of vision, or how the retina works.]

4-PS4-3. Generate and compare multiple solutions that use patterns to transfer information.* [*Clarification Statement*: Examples of solutions could include drums sending coded information through sound waves, using a grid of 1s and 0s representing black and white to send information about a picture, and using Morse code to send text.]

**This performance expectation integrates traditional science content with engineering through a practice or disciplinary core idea.*

Science and Engineering Practices

Developing and Using Models
Modeling in 3–5 builds on K–2 experiences and progresses to building and revising simple models and using models to represent events and design solutions.
- Develop a model using an analogy, example, or abstract representation to describe a scientific principle. (4-PS4-1)
- Develop a model to describe phenomena. (4-PS4-2)

Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.
- Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution. (4-PS4-3)

Connections to Nature of Science

Scientific Knowledge Is Based on Empirical Evidence
- Science findings are based on recognizing patterns. (4-PS4-1)

Disciplinary Core Ideas

PS4.A: Wave Properties
- Waves, which are regular patterns of motion, can be made in water by disturbing the surface. When waves move across the surface of deep water, the water goes up and down in place; there is no net motion in the direction of the wave except when the water meets the beach. *(Note: This grade band endpoint was moved from K–2.)* (4-PS4-1)
- Waves of the same type can differ in amplitude (height of the wave) and wavelength (spacing between wave peaks). (4-PS4-1)

PS4.B: Electromagnetic Radiation
- An object can be seen when light reflected from its surface enters the eyes. (4-PS4-2)

PS4.C: Information Technologies and Instrumentation
- Digitized information can be transmitted over long distances without significant degradation. High-tech devices, such as computers or cell phones, can receive and decode information—convert it from digitized form to voice—and vice versa. (4-PS4-3)

ETS1.C: Optimizing the Design Solution
- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. *(secondary to 4-PS4-3)*

Crosscutting Concepts

Patterns
- Similarities and differences in patterns can be used to sort and classify natural phenomena. (4-PS4-1)
- Similarities and differences in patterns can be used to sort and classify designed products. (4-PS4-3)

Cause and Effect
- Cause and effect relationships are routinely identified. (4-PS4-2)

Connections to Engineering, Technology, and Applications of Science

Interdependence of Science, Engineering, and Technology
- Knowledge of relevant scientific concepts and research findings is important in engineering. (4-PS4-3)

See connections to 4-PS4 on page 140.

Teacher Guidance Including a 5E Mini-unit Outline

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 13 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 groups of three or four. A model lesson sequence for use of the stations appears below. Each day would involve a 50-minute session. The activities and strategies represent attempts to bring about a student-friendly and integrated experience for your students.

The 5E plan model utilized in this packet comes from the 5E learning cycle and its five stages: Engage, explore, explain, elaborate and evaluate. This model encourages and promotes inquiry based learning and allows students to build science meaning through experience and reflective thought. If you would like more information on the 5E model, please consult the Midwestern State University (MSU) or NASA websites below.

http://faculty.mwsu.edu/west/maryann.coe/coe/inquire/inquiry.htm

http://www.nasa.gov/audience/foreducators/nasaeclips/5eteachingmodels/

A sample teaching outline: 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?" 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. Use the following outline for ideas.

- Day one: Establish context, do pre-teaching.(Engage)
  - Create KWL chart
  - Create Cognitive Content Dictionary (CCD) and use "wave" as your first input. (Other terms for CCD could include frequency, wavelength, amplitude, reflection or refraction)
  - Allow students to freely explore stations for 15 minutes.
  - Direct instruction of descriptors (see pre-teaching section below).
- Day two: Ask the student groups for deeper engagement at the stations during which students will record their work on the student handouts. (Explore)
  - Review KWL chart focusing on what the students WANT to know.
  - Review the term "wave" in the CCD.
  - Introduce each station to the students.
  - Put students into group and give them "wave packet."
  - Allow students to begin rotations.

- Day three: Check for student ideas and questions. Undertake vocabulary development. Provide time for students to complete the stations. (Explore)
    - Review CCD, ask for student input into next two entries on the CCD.
    - Review station expectations.
    - Begin student station rotations.
    - Remind students that this is the last day for exploration.
- Day four: Sense-making (Explain)
    - Review CCD and add final vocabulary
    - Introduce and read informational text as a whole group using close reading strategies.
    - Give overview of “Expert panel” activity. Students will be put into groups with one station as their focus. Each group will come to conclusions and share with the whole class. Then the students can weigh in and the teacher can make adjustments of the understandings as needed.
    - Teacher should clarify as each group presents.
- Day 5: Elaborate with Bill Nye the Science Guy video and “Black Hole Hunter” game.
    - Review CCD input chart
    - Prepare students to watch the “Bill Nye the Science Guy video” with the purpose of confirming or enhancing their understanding of waves.
    - Give the students opportunity using the COWS to play “Black Hole Hunter”
    - Make an input chart that makes connections between these extensions and the knowledge derived from the stations.
- Day 6: Review using poster and informational text. Follow with assessment. (Evaluate)
    - Review and complete KWL chart.
    - Review CCD vocabulary.
    - Assessment

Several safety items will require attention.

- Don’t let go of the Slinky when the Slinky is stretched.
- The Slinky may have sharp edges, please tape or throw away broken Slinkys
- When using rope for various activities, please inform students of proper use (i.e. not hitting others)
- When water is used in an activity, remind students to keep the water contained to prevent slipping and falling situations
- The tuning forks should be used carefully so students to do hit others or themselves

- When using various lenses in this packet, please warn students not to look at direct Sunlight

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.

Vocabulary development: In pilot testing, fourth grade students frequently used the words “big” and “small” to describe a number of different comparisons at the stations, creating confusion between different types of comparisons. As the students make progress in the wave lessons, teachers might want to review other descriptor pairs to help students generate clearer descriptions. Some students might not be familiar with pitch as a sound descriptor.

- A time can be long or short
- An up-down measurement can be tall or short
- A sideways measurement can be tall or short
- A sound can be loud or quiet
- A sound can have a high pitch or low pitch

Timing the Stations: 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.

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

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

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

<u>Waves in a rain gutter</u>
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.

<u>Waves in a ripple tank</u>
Students observe circular and linear waves moving through water at different frequencies.

<u>Waves in a cake pan (alternative to ripple tank)</u>
Students observe circular and linear waves moving through water at different frequencies.

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

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

<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.

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

<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

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

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

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

<u>Sound through a tin can telephone</u>
Two students will send sound messages through a wire that connects a pair of tin can telephones

<u>Transferring sound onto light</u>
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.

Alignment between the activities and 4-PS4 DCI's

4-PS4-1. Develop a model of waves to describe patterns in terms of amplitude and wavelength and that waves can cause objects to move

- Waves on a Slinky
- Waves on a rope
- Waves in a rain gutter
- Waves in a ripple tank
- Waves on pencils
- A vibrating ruler
- Measuring sound waves on a computer
- A pair of tuning forks

4-PS4-2: Develop a model to describe that light reflecting from objects and entering the eyes allows objects to be seen

- Reflections from a flat mirror
- Reflections from a curved mirror
- Light through curved lenses

4-PS4-3: Generate and compare multiple solutions that use patterns to transfer information

- Light through fiber optic cable
- Sound through a tin can telephone
- Transferring sound onto light

Alignment between activities and Science and Engineering practices

Developing and Using Models

4-PS4-2: Develop a model to describe natural phenomena

- Stations include students making models that build their understanding of waves.
- Students will make a model to demonstrate the transfer of information.

Constructing Explanations and Designing Solutions

4-PS4-3: Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solutions

- "Expert" panel and student derived explanations exhibit the students ability to generate and compare multiple solutions

Scientific Knowledge is Based on Empirical Evidence

4-PS4-1: Science findings are based on recognizing patterns

- Students will recognize the pattern of waves throughout the mini-unit

Alignment between activities and ELA Common Core

CCSS-Language.4.6

Acquire and use accurately grade-appropriate general academic and domain-specific words and phrases, including those that signal precise actions, emotions, or states of being (e.g., quizzed, whined, stammered) and that are basic to a particular topic (e.g., *wildlife, conservation,* and *endangered* when discussing animal preservation).

CCSS.ELA-Literacy.W.4.9

Draw evidence from literary or informational texts to support analysis, reflection, and research.

Activity setup instructions

<u>Waves on a Slinky</u>

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

<u>Waves on a rope</u>

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.

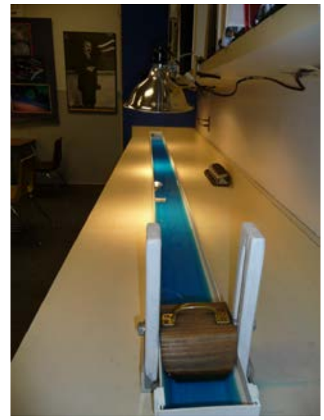
Notes:

- 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.

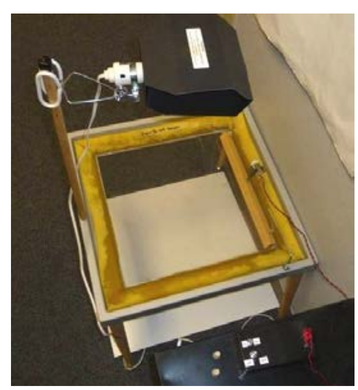
Notes:

- 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

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



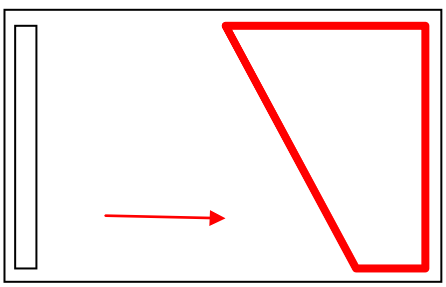
Setup:

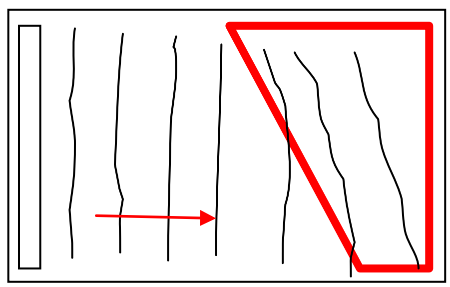
- If you purchase a ripple tank apparatus from a supplier, the apparatus will come with assembly instructions. The setup takes some time and is a bit complicated, but the results are very good if you can obtain a suitable level of performance.
- **OUR PREFERRED SUBSTITUTE:** A large shallow cake pan 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).



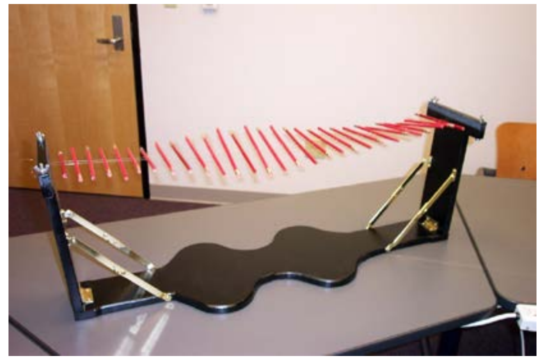


- Safety: One of the drawbacks of the commercial ripple tank kit is that the light source becomes very hot. It's shielded in an encasement, but some teachers elect to avoid the apparatus because of this concern

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

A vibrating ruler

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 station doesn't take as long as some of the others to complete.

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

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.

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

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

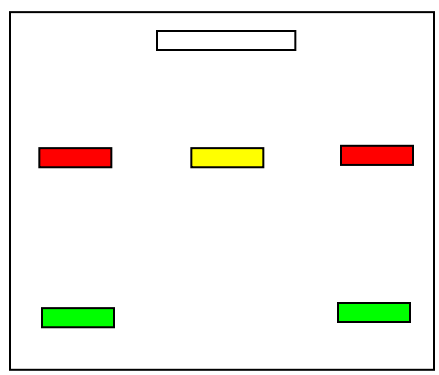
Item	*Source*	*Item Number*	*Cost*
Resonant tuning forks	Flinn Scientific	AP5724	122

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

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.

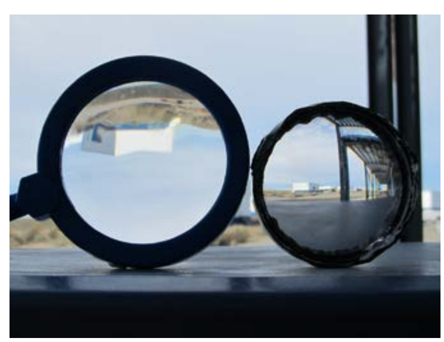
Notes:

- 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:

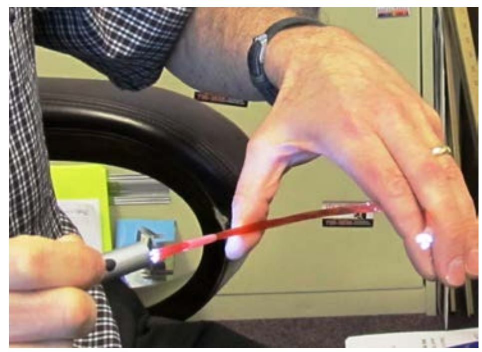
- Ensure that the students can't break the lenses through normal use. Consider wrapping the circumference of the inward curving lens with a number of wraps of duct tape to cushion the glass. The outward curving lenses (magnifiers) are plastic.

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

<u>Light through fiber optic cable</u>
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

<u>Sound through a tin can telephone</u>
Two students will 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.

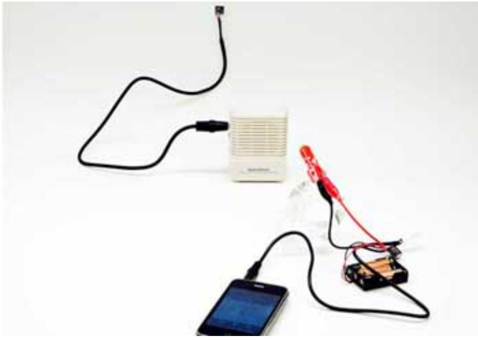
Notes:

- 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

<u>Transferring sound onto light</u>

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

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 slowly. Sketch the wave pattern in the space below. Use arrows to show the direction of the waves.

2. Now person should move the end back and forth very quickly. Sketch the new wave pattern in the space below. Include arrows to show the directions of the waves.

3. How are the first and second wave patterns different?

4. Do the waves get longer or shorter as you move the end of the Slinky faster?

5. What happens to a Slinky wave when it reaches the end of the Slinky?

6. What **energy** source created the waves on the Slinky?
   A. Gravity   B. Human   C. Air   D. Sun

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. Sketch the wave pattern in the space below. Use arrows to show the direction of the waves.

2. Now one person should move the end back and forth very quickly. Sketch the new wave pattern in the space below. Include arrows to show the directions of the waves.

3. Do the waves get longer or shorter as you move the end of the rope faster?

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

5. How can you make the waves on the rope longer?

Waves in a Rain Gutter

Push down on the water, with the plunger, 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 gutter?

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?

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?

Make four waves quickly.

4. How much space is between the waves as they move? Draw a diagram .

Make four waves slowly.

5. How much space is between the waves this time? Draw a diagram.

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?

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 and watch the cork as the waves go by. Move the long piece of wood up and down **slowly** and watch the waves. Now move the piece of wood up and down **quickly** and watch the 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).
   A. Reflection B. Refraction C. Response D. Wave

2. What do you need to do to make tall waves at this station?

3. What do you need to do to make long waves 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

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.

   A. Quiet B. Loud

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 ______________ pitch.

   A. Low B. High

Student Handout

Using a Computer to Measure Sound Waves

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

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

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. What do you think causes the mirror to change your **reflection** so much? What's special about the mirror?

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. Do they feel flat? Do they feel the same as each other?

4. What's the connection between the shape of the lens and what you see through the lens?

5. What does this experiment teach us about light going through lenses?

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. We can change the direction of light by using a _ _ _ _ _ _ _.
   A. Compass B. Mirror C. Cable D. Light

5. The glass inside the cable acts like many __________, causing the light to change direction and follow the curve of the cable.
   A. Lights B. Mirrors C. Televisions D. Phones

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?

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 once but probably won't win it again. Most things, however, don't just happen once – they happen over and over again and follow some sort of pattern. You celebrate your birthday once a year. You eat lunch once a day. Your heart beats about once a second. A car tire might spin 10 times a second. Processes that happen over and over again in the same way are called **periodic**. One of the most basic questions we can ask is "How much time is needed for a periodic pattern to happen once?" This time, the length of time for one cycle of a pattern, is named the **period** of the pattern. What are the periods of the following events?

- A clock cycle (12 hours)
- The bus ride to school (One day – you ride the bus to school once a day)
- 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)

If we ask "How long does one cycle last?" we call the answer the **period**. If we ask "How many times does the cycle happen in one second?" we call the answer the **frequency**. Here are some common events and their frequencies.

- Vultures flap their wings about once per second.
- Some hummingbirds can flap their wings 90 times per second.
- Your vocal cords can vibrate a thousand times per second.
- Light waves can vibrate trillions of times per second.

Vibrations can transfer energy to their surroundings as **waves**. Whatever carries the waves is called the **medium** for the waves. The medium for sound waves usually is the air. The medium for earthquake waves is the ground. Waves are traveling vibrations. They have periods and frequencies. Because waves travel across distances, they also have **wavelengths**. And because waves travel from one place to another, they have **speeds**.

Transverse waves vibrate sideways (or up and down). **Longitudinal** or **compression** waves vibrate in the direction that they travel.

Transverse waves can be tall or short. Compression waves can be very squished and very stretched or only a little stretched and a little squished. We use the word **amplitude** to describe this property of waves.

All waves can **reflect** (bounce off an obstacle) and **refract** (change their direction because of a change in the medium).

Waves can **transmit information** from one place to another. You transmit information by sound waves when you talk. Cell phones use microwaves for information transfer. Some hand-held remotes use infrared waves. Communications companies send light through fiber optic cable for information transfer. Astronomers gather information from outer space by capturing light waves in their telescopes and other devices. LIGO also wants to gather information from outer space by detecting gravitational waves.

You may have heard of "digital communications." Engineers can convert the frequencies and amplitudes of waves to strings of electrical ones and zeroes. These strings of ones and zeroes can be sent from place to place. When you watch TV, the information on your screen came to the TV as strings of ones and zeroes and your TV converts this digital information to colors and sounds.

Situational Assessment

DCI ETS1.C Optimizing the Design Solution Information Transfer Design Challenge

CCSS.ELA-Literacy.W.4.9 Draw evidence from literary or informational texts to support analysis, reflection, and research.

<u>Situation</u>:
You have written ten words of information. You need to give the information to your partner. You are on one side of a wall and your partner is on the other side. Perhaps you are in your classroom and your partner is out in the hall. How will you transfer the information? There might be a door in the wall, but you can't just open the door and hand your partner a piece of paper. You need to think of a different way of transferring the information. You can use technology, but you can't use technology that someone has already invented to do the same job, like a cell phone. You need to come up with your own method.

Below describe your method, the materials that you will need, and the reasons why your design is optimal to other methods using the informational text provided during this unit to support your analysis.

Vocabulary Matching

Draw a line connecting the corresponding term and definition.

Terms	**Definitions**
Waves	Change in the direction of the wave
Reflection	Periodic transfer of energy
Refraction	Wave bouncing off of an obstacle
Sound information	Rate of wave cycles
Frequency	Cell phone technology
Speed	The rate wave moves AWAY from the source
Period	Time for motion to repeat itself
Amplitude	Distance over which the wave repeats
Wave length	Extent of vibration

Student Scientists' Survey

Check off how well each of these activities helped you learn about waves	My favorite	I liked this	I did not like this
Watching demonstrations			
Hands-on stations			
Reading about waves			
Working with a partner			
Working in small groups			
Presenting your ideas to the class			
Watching "Bill Nye the Science Guy"			
Playing "Black hole hunter"			
Asking questions in class			
Cognitive Content Dictionary resource			
Class discussions			

What was your favorite activity and why?

____
____
____
____

What would you have liked to spend more time working on?

____
____
____
____

Sample Reponses for the Student Handouts

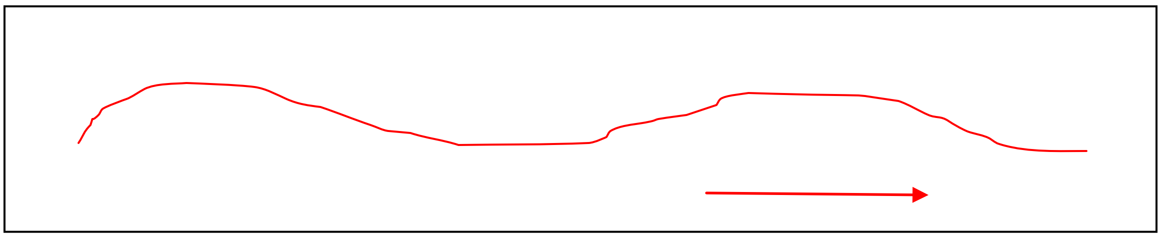
This mini-unit and the wave stations should encourage both teacher and student to engage in inquiry-based explorations while building an understanding of the science of waves. The process of science involves struggle; science teaching usually improves when teachers experience the struggle along with 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 slowly. Sketch the wave pattern in the space below. Use arrows to show the direction of the waves.



2. Now person should move the end back and forth very quickly. Sketch the new wave pattern in the space below. Include arrows to show the directions of the waves.

3. How are the first and second wave patterns different?

   The waves in the second pattern are more crowded; they're shorter

4. Do the waves get longer or shorter as you move the end of the Slinky faster?

   Shorter

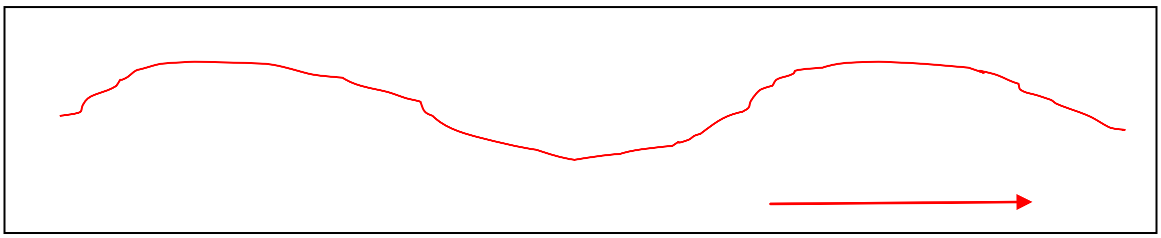
5. What happens to a Slinky wave when it reaches the end of the Slinky?

   It bounces back

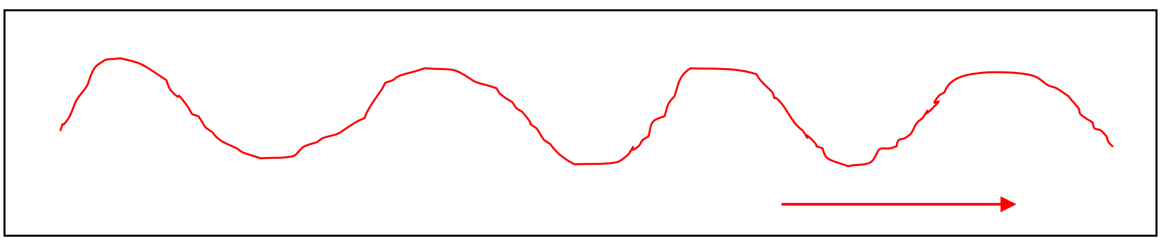
6. What energy source created the waves on the Slinky?
   B. Gravity   B. Human   C. Air   D. Sun

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. Sketch the wave pattern in the space below. Use arrows to show the direction of the waves.



2. Now one person should move the end back and forth very quickly. Sketch the new wave pattern in the space below. Include arrows to show the directions of the waves.



3. Do the waves get longer or shorter as you move the end of the rope faster?

   Shorter

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

   Move my hand and arm more – make a bigger motion.

5. How can you make the waves on the rope longer?

   Move my hand and arm more slowly.

Student Handout

Waves in a Rain Gutter

Push down on the water, with the plunger, 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 gutter?

   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?

   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?

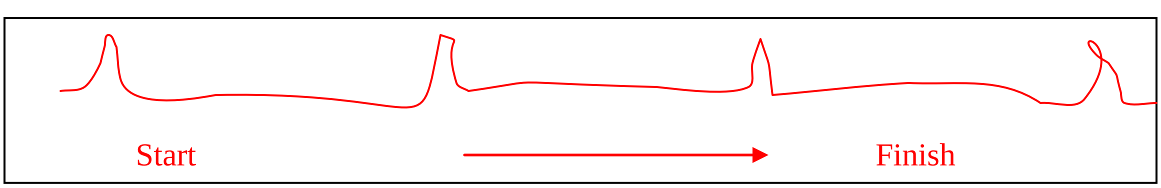
   The cork moves sideways a little bit but not much. It mainly bobs up and down.

Make four waves quickly.

4. How much space is between the waves as they move? Draw a diagram.

Now make four waves slowly.

5. How much space is between the waves this time? Draw a diagram.

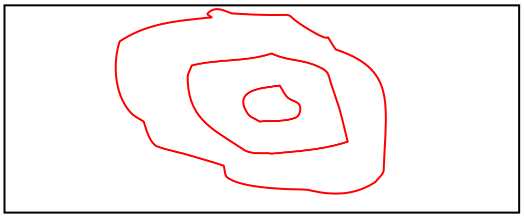


Student Handout

Waves in a Ripple Tank

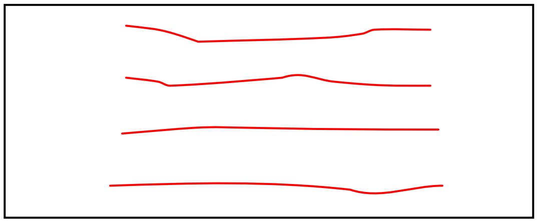
Make circular waves in the water by using the round ball on the end of the vibrating rod.

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 in 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.

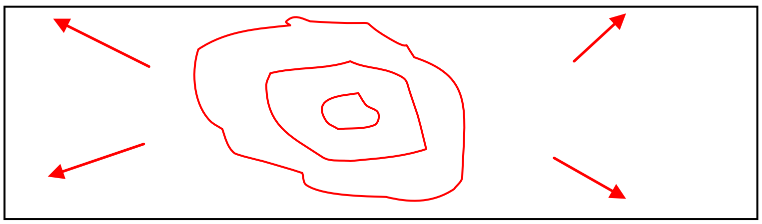
6. What happens to the waves when they reach the angled board?
The waves change direction. They bend to follow the angle of the board

Student Handout

Waves in a Cake Pan

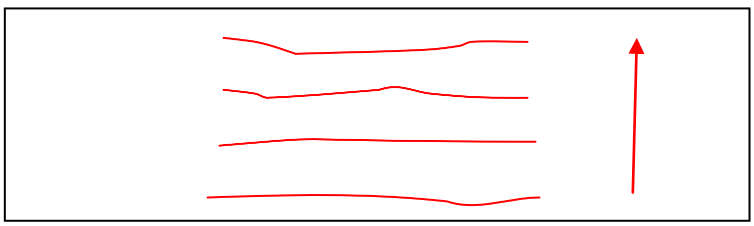
Let the water become very still. Squeeze a single drop of water into the center of the pan.

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 and watch the cork as the waves go by. Move the long piece of wood up and down **slowly** and watch the waves. Now move the piece of wood up and down **quickly** to watch the waves.

3. How does the wave pattern change when you change how quickly you move the wood up and down?

When you move the wood up and down quickly, the waves are close together

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

My hand moving the wood is the energy source for the waves.

5. When you see a wave moving through the water, is the water moving along with the wave? How do you know?

The cork doesn't move sideways much, so the water must not move much.

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, the 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).
   B. Reflection B. Refraction C. Response D. Wave

2. What do you need to do to make tall waves at this station?

   You make a tall wave by moving the pencils a lot with your hand – twisting a lot.

3. What do you need to do to make long waves at this station?

   Move your hand back and forth slowly

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

   The waves lose energy somehow

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

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 low-pitch twanging sound

Now pluck harder.

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

   The sound gets louder

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

   The end of the ruler moves up and down a lot more

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

   B. Quiet B. Loud

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 end of the ruler moves up and down faster – it gets very blurry

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 ______________ pitch.

   B. Low B. High

Student Handout

Using a Computer to Measure Sound Waves

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.

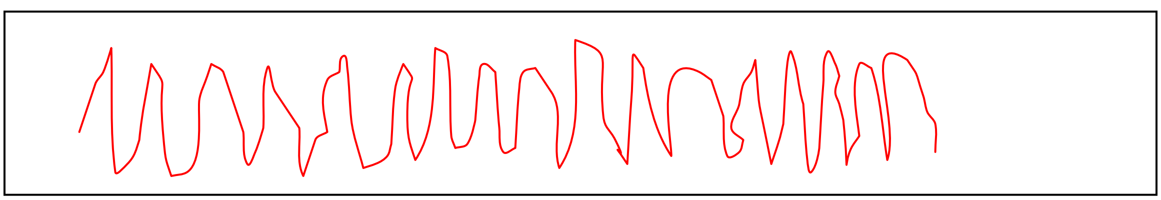
1. What do you hear after you tap the fork and hold it close to your ear?
   One sound – a single note

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.

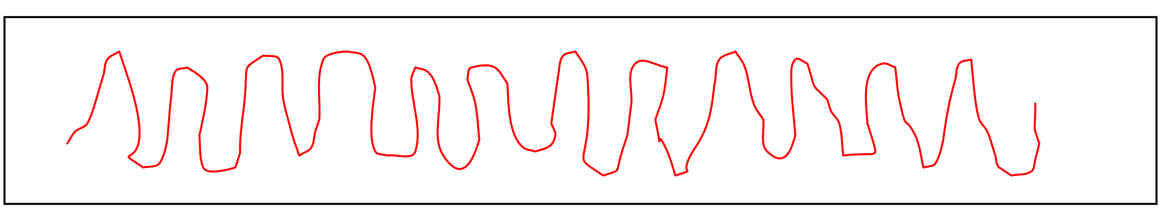


Now find the long fork again. Tap it and hold it close to the microphone. Watch the screen.

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



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. 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

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.

I see myself but not my partner. My partner can see himself or me.

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, we can see each other 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?
   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?

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. What do you think causes the mirror to change your reflection so much? What's special about the mirror?

The mirror curves inward. The curve must change the direction of the reflected light.

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

    In one lens my hand looks bigger, in the other it looks 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.

    What I see through the magnifying glass now is upside down.. In the other lens, things just look really small.

Carefully run your fingers across the lenses.

3. Do they feel flat? Do they feel the same as each other?

    They're not flat. One curves inward, the other curves outward.

4. What's the connection between the shape of the lens and what you see through the lens?

    The lens that curves outward makes thing look big or upside down. The lens that curves inward makes everything look small.

5. What does this experiment teach us about light going through lenses?

    Light will change direction when it goes through a curved lens.

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. We change the direction of light by using a _ _ _ _ _ _.
   B. Compass B. Mirror C. Cable D. Light

5. The glass inside the cable acts like many __________, causing the light to change direction and follow the curve of the cable.
   B. Lights B. Mirrors C. Televisions D. Phones

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).

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.

6. How much space is between the waves as they move? Draw a diagram .

Table Signs for the Student Activities

Cut out these labels and instructions and place them on the tables where the activities will be located.

Waves on a Slinky

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 slowly. Now person should move the end back and forth very quickly.

Waves on a Rope

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. Now one person should move the end back and forth very quickly.

Waves in a Rain Gutter

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

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

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

Make four waves slowly.

Waves in a Ripple Tank

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

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

Change the speed of the motor slightly. Put a cork on the water and 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.

Waves in a Cake Pan

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

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.

Put a cork on the water and watch the cork as the waves go by. Move the long piece of wood up and down **slowly** and watch the waves. Now move the piece of wood up and down **quickly** and watch the waves.

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.

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.

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.

Now pluck harder.

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

Using a Computer to Measure Sound Waves

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.

Now try a long tuning form.

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

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

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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.

Now tap the fork again and this time touch it 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.

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.

Reflections from a Flat Mirror

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

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

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

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.

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.

Reflections from a Curved Mirror

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

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).

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.

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.

Carefully run your fingers across the lenses.

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.

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.

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

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

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