Science News

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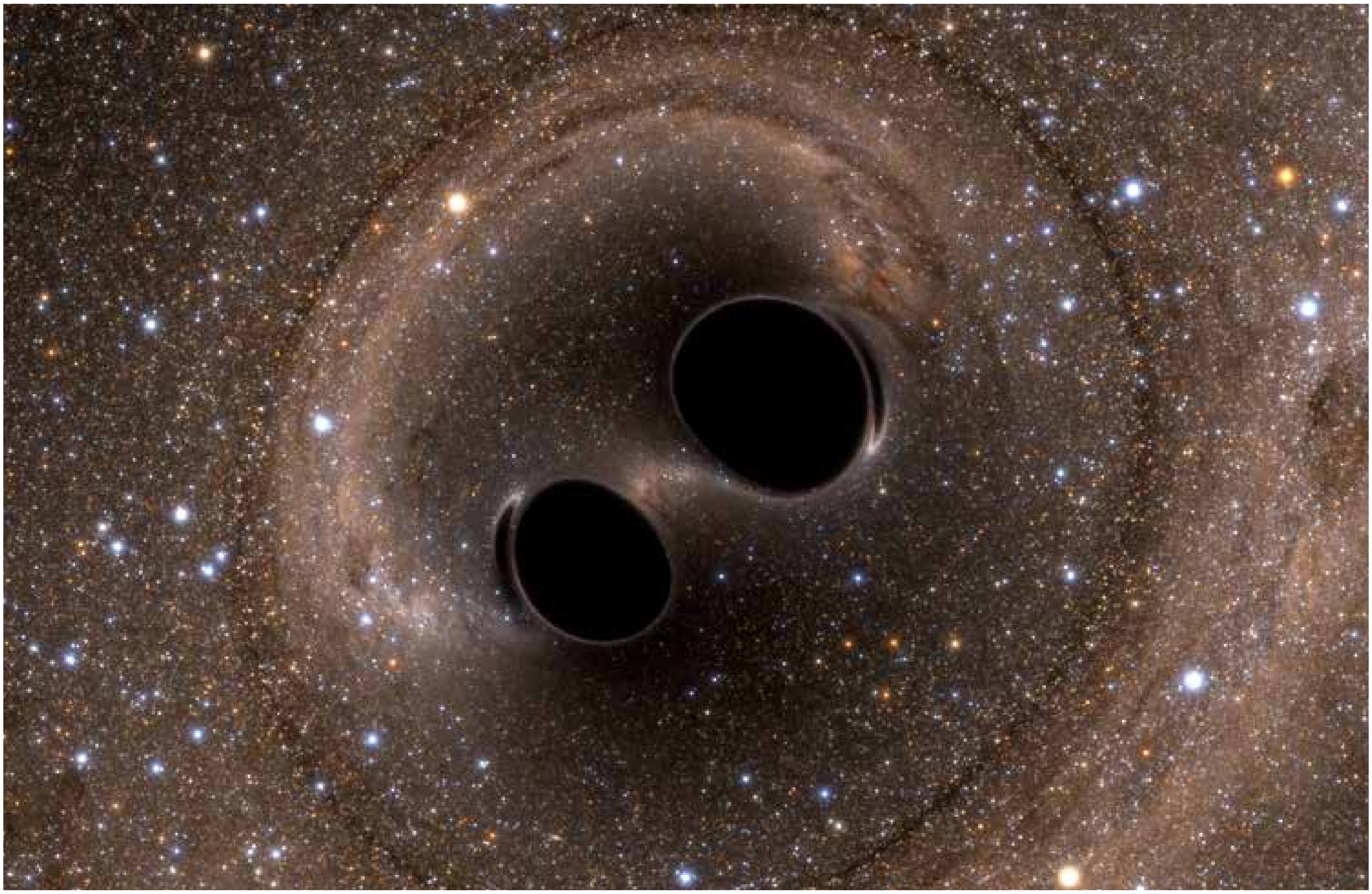

Dec. 24, 2016 & Jan. 7, 2017

Making Waves

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EDUCATOR GUIDE

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About this Issue

Science News' latest issue looks back at impactful research "making waves" in 2016. The No. 1 story of the year, "Gravitational waves offer new view of dynamic cosmos" (Page 17), recounts the direct detection of gravitational waves, reported for the first time in 2016. Albert Einstein's theory of general relativity had predicted the waves a century earlier. The article also describes how observing gravitational waves could tell us more about collisions between black holes, explosions of stars and other cosmic events that create the waves. A special infographic, "The future of cars" (Page 34), examines the challenges in developing and embracing self-driving cars. How will humans share the roads with robotic vehicles that don't have the instincts and ethics that help us make decisions? Cognitive scientists and robotic engineers are joining forces to overcome problems with sensory perception, spatial awareness, safety and cybersecurity. The infographic text touches on robotics, physiology and psychology, cyber vulnerability and social and ethical considerations. Students can focus on the details of each article or explore cross-curricular connections to other major science topics such as wave interference or automated technology. For additional gravitational wave information and curriculum-related content, see the *Science News* article "Physicists detect gravitational waves," in the March 5, 2016 issue, and the accompanying Educator Guide.

Connections to Curricula

- Qualitative observations
- Theory of general relativity
- Waves and vibration
- Optics and lasers
- Ethics
- Spatial organization
- Brain physiology
- Sociology and human interactions
- Robotics
- Cybersecurity

What's in this Guide?

- Article-Based Observation on Self-Driving Cars: These questions focus on reading and content comprehension by drawing on information found in the article "The future of cars." Questions focus on autonomous vehicles and the nature of research that will support their widespread use.
- Article-Based Observation on Gravitational Waves: These questions develop an understanding for the concept of gravitational waves by focusing on gravitational waves, gravitational wave detectors and how observing gravitational waves can improve our understanding of the universe. The questions are based on an article from this issue, "Gravitational waves offer new view of dynamic cosmos," and the related article from the March 5, 2016 issue, "Physicists detect gravitational waves."
- Quest Through the Archives: With Internet access and your school's digital access to *Science News*, your students can use this short section to explore applications of artificial intelligence and the potential issues with its use, as reported by *Science News* since 1922.

- Cross-Curricular Discussion: These questions and extension prompts connect to the article "Gravitational waves offer new view of dynamic cosmos" and encourage students to think about many types of waves and wave detectors. The section is divided roughly by science subdiscipline for educators who would like to focus on one particular topic area. The extension prompts are either more topic specific or more conceptually advanced. **Biological Sciences** questions cover detection of various types of waves by humans and other animals. **Physical Sciences** questions concern general properties of waves, differences between sound and electromagnetic waves and the nature of gravitational waves. **Earth-Space Sciences** questions encourage students to think about events in space that can produce gravitational waves. **Engineering and Experimental Design** questions focus on how to design wave detectors and how to interpret collected data correctly.
- Activities: This section includes two experimental activities that students can perform. The first activity on **Wave Generation** involves generating and observing waves in a clear pan of water, with analogies to gravitational waves and to the light waves used in gravitational wave detectors. The second activity on **Wave Detection** asks students to design, build, test and optimize their own light-based detector for waves (a very simple optical seismometer), and explores how this detector relates to much more sophisticated gravitational wave detectors.

Standards Alignment

Next Generation Science	Common Core
Energy: HS-PS3-2, HS-PS3-5	ELA Standards: Reading Informational Text (RI): 1, 2, 4, 7
Waves and their Applications in Technologies for Information Transfer: HS-PS4-1, HS-PS4-5	ELA Standards: Writing (W): 1, 2, 8, 9
Earth's Place in the Universe: HS-ESS1-2	ELA Standards: Speaking and Listening (SL): 1, 2, 3, 4
Engineering Design: HS-ETS1-1, HS-ETS1-3	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 9
	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 1, 2, 4, 7, 9

Article-Based Observation on Self-Driving Cars

Directions: After reading the article "The future of cars," answer these questions:

1. **Though cars are not organisms with nervous systems, autonomous cars need to adapt and react to their environment. What are the basic goals of a self-driving car's sensory system? How do autonomous cars navigate their surroundings?**

2. **What are some factors that limit self-driving cars' abilities to respond to unexpected situations?**

3. **How does Chris Janssen's work as a cognitive scientist further research into self-driving cars? What is a possible hypothesis he could develop and study?**

4. **What ethical and social dilemmas must be considered in the design of the autonomous car? What basic tenet of human behavior did Iyad Rahwan mention as a potential obstacle?**

5. **Cybersecurity and hacking are a general concern in our interconnected, digital world. How might these threats affect the self-driving car, as described in the article?**

Responses to Article-Based Observation on Self-Driving Cars

1. **Though cars are not organisms with nervous systems, autonomous cars need to adapt and react to their environment. What are the basic goals of a self-driving car's sensory system? How do autonomous cars navigate their surroundings?** Possible student response: Self-driving cars need sensors that can detect road features and hazards under any condition. Autonomous cars navigate by analyzing data from sensors and comparing it with existing maps. Some cars have onboard cameras that could update maps as surroundings change.

2. **What are some factors that limit self-driving cars' abilities to respond to unexpected situations?** Possible student response: Responding to unexpected encounters is a struggle for artificial intelligence. Rule-based programming will not always work for self-driving cars, because the coding would need to exist for every potential environment and condition. If an autonomous car isn't programmed to read the body signals of every pedestrian, for example, that pedestrian's safety is dependent on him or her correctly predicting the movements of the car.

3. **How does Chris Janssen's work as a cognitive scientist further research into self-driving cars? What is a possible hypothesis he could develop and study?** Possible student response: Chris Janssen studies where people put their attention and how they react when they are not giving their full attention to an activity. In the case of self-driving cars, he is studying when instructions should be given to a passenger to take over driving and how to give those instructions. One possible hypothesis: The earlier an alert for a change in behavior is given, the more quickly a person will respond.

4. **What ethical and social dilemmas must be considered in the design of the autonomous car? What basic tenet of human behavior did Iyad Rahwan mention as a potential obstacle?** Possible student response: Cognitive scientist Iyad Rahwan has found that people want to protect themselves, regardless of whether they are in the car or a pedestrian. Who will the cars prioritize? Who will be responsible when the cars fail? How the technology develops and how it is regulated will depend on the moral judgments of designers and consumers.

5. **Cybersecurity and hacking are a general concern in our interconnected, digital world. How might these threats affect the self-driving car, as described in the article?** Possible student response: According to Sean Smith, a computer scientist at Dartmouth College, "the more computing permeates into everyday objects, the harder it is going to be to keep track of the vulnerabilities." Self-driving cars will be no exception. Mechanical systems could be wirelessly controlled. Cars might be remotely programmed to crash or systems could be disabled and held for ransom.

Dec. 24, 2016 & Jan. 7, 2017
Making Waves

Article-Based Observation on Gravitational Waves

Directions: Read the article "Gravitational waves offer new view of dynamic cosmos," as well as the earlier article "Physicists detect gravitational waves," which gives important background information. Then answer these questions:

1. **What is the main topic of the articles?**

2. **What is spacetime?**

3. **What are gravitational waves?**

4. **How were gravitational waves detected?**

5. How were the detected gravitational waves created?

6. Why is the first direct detection of gravitational waves so significant?

7. What can scientists find out from studying gravitational waves?

8. How do scientists plan to tell which direction gravitational waves are coming from?

Dec. 24, 2016 & Jan. 7, 2017
Making Waves

Responses to Article-Based Observation on Gravitational Waves

1. **What is the main topic of the articles?** Possible student response: Scientists directly detected gravitational waves for the first time.

2. **What is spacetime?** Possible student response: Spacetime combines the three dimensions of space plus the fourth dimension of time into a single continuum.

3. **What are gravitational waves?** Possible student response: Gravitational waves are ripples in spacetime, like ripples produced on a rubber sheet when a massive object is moved on it.

4. **How were gravitational waves detected?** Possible student response: Gravitational waves were detected by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO). LIGO uses interference between laser beams traveling up and down the arms of its L-shaped detectors to look for signs of the waves. Gravitational waves stretch and compress empty space itself, ever so slightly changing the lengths of the detector arms and thus changing how the laser beams interfere.

5. **How were the detected gravitational waves created?** Possible student response: The gravitational waves were created by two massive black holes spiraling around each other and merging together.

6. **Why is the first direct detection of gravitational waves so significant?** Possible student response: Gravitational waves were predicted by Albert Einstein's theory of general relativity a century ago, so this discovery confirms Einstein's predictions. Gravitational waves tend to be very weak when they reach Earth (with spacetime only expanding and contracting by a minute amount, like a fraction of the width of a proton), so detecting them required both a very strong source (massive colliding black holes) and a very large and very sensitive detector (which was not possible until recently). The detection also creates a new field of astronomy through which scientists can understand the universe.

7. **What can scientists find out from studying gravitational waves?** Possible student response: By observing gravitational waves, scientists can study the properties of black holes as they collide, compare the gravitational waves and visible light produced by neutron star collisions or star explosions, and check Einstein's theory of general relativity to see if its predictions are very accurate or need to be corrected for certain circumstances.

8. **How do scientists plan to tell which direction gravitational waves are coming from?** Possible student response: With three gravitational wave detectors (Virgo plus LIGO detectors in two locations), scientists can compare the timing of the gravitational wave signals arriving at each detector to determine which direction the waves are coming from.

Making Waves

Quest Through the Archives

Directions: After reading the article “The future of cars,” use the archives at www.sciencenews.org to answer these questions:

1. **Search for an article discussing artificial intelligence and smart sensing. How are roboticists “embodying smarts in their creations”?**

2. **Search for an article that examines the need for cybersecurity. How can cyber attacks affect the functionality of technology?**

3. **Humans respond to the world in all sorts of ways that artificial intelligence doesn’t — at least not yet. Find an article that talks about how the brain reacts to fear. What does it say about the necessity of this reaction?**

Responses to Quest Through the Archives

1. **Search for an article discussing artificial intelligence and smart sensing. How are roboticists "embodying smarts in their creations"?** Possible student response: Robots can use laser sensors to collect data and, using math, can compare collected data to stored maps of their surroundings. This technology allows robots to better sense what is going on around them. https://www.sciencenews.org/article/artificial-intelligence-needs-smart-senses-be-useful

2. **Search for an article that examines the need for cybersecurity. How can cyber attacks affect the functionality of technology?** Possible student response: Communication channels used for capturing images and video on certain cellphones can be hacked to attack a cellphone's battery. Hackers might turn on an idle phone and drain its battery power. https://www.sciencenews.org/article/cyber-attack-depletes-cell-phone-batteries

3. **Humans respond to the world in all sorts of ways that artificial intelligence doesn't — at least not yet. Find an article that talks about how the brain reacts to fear. What does it say about the necessity of this reaction?** Possible student response: "Infant brains have powerful reactions to fear" discusses the idea that the network of nerves in humans that let us respond to external stimuli is essential to survival. https://www.sciencenews.org/article/infant-brains-have-powerful-reactions-fear

Cross-Curricular Discussion

After students have had a chance to review the article "Gravitational waves offer new view of dynamic cosmos," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your classroom into a different document for your students. Before starting the discussion, consider having students watch these videos: *Science News* answers the question "What are gravitational waves?" and Stephen Colbert discusses gravitational waves and detectors with theoretical physicist Brian Greene.

BIOLOGICAL SCIENCES

Discussion Questions:

1. What types of waves can humans and other animals detect? [*Sound waves, light waves, waves on a surface, etc.*]
2. What methods do humans and other animals use to detect those waves? How do their natural wave detectors work? [*Have diagrams of how the eye, ears, tactile senses and so on function.*]

Extension Prompts:

3. What can humans and other animals learn about their environment by detecting various types of waves? [*Consider information that can be gleaned from sight, sound and touch, but also consider examples that go beyond human sensory abilities such as bats using sonar, spiders detecting vibrations, insects sensing ultraviolet waves from the sun, snakes detecting infrared waves from prey, for example.*]
4. What extra wave detection abilities do you wish your body had? How might that work, and what would you use it for? [*Student responses will vary.*]
5. Compare and contrast ripples in spacetime with ripples in a food web. [*Student responses will vary.*]

Biological Sciences Question Bank:

What types of waves can humans and other animals detect?

What methods do humans and other animals use to detect those waves?

What can humans and other animals learn about their environment by detecting those various types of waves?

What extra wave detection abilities do you wish your body had? How might that work, and what would you use it for?

Compare and contrast ripples in spacetime with ripples in a food web.

PHYSICAL SCIENCES

Discussion Questions:

To illustrate these concepts as you go, it is very helpful to use a Slinky (approximately $3.00 at Walmart or similar stores). Have a student stand at one front corner of the classroom and hold one end of the Slinky, while you hold the other end and stretch it across the front of the classroom. The student should keep his or her end still at all times, allowing you to create the desired type of wave. Alternatively, you can hold your end still and ask the student to create wave types. To talk about wave interference, you can use two Slinky toys stretched out side by side. You'll also need a rubber sheet or plastic wrap.

1. What are the major properties of a wave? [*Illustrate amplitude, wavelength, frequency, velocity and so on with the Slinky.*]

2. What is the difference between transverse and longitudinal waves? [*Wiggle the Slinky up and down to make transverse waves. Send one quick compression wave straight through the Slinky toward the student to illustrate longitudinal waves.*]

3. What is the polarization of a transverse wave? [*Vertically polarized waves on a Slinky wiggle up and down, whereas horizontally polarized waves on a Slinky wiggle side to side.*]

4. What is the difference between a traveling and standing wave? [*Traveling waves continue to move forward in space; give the end of the Slinky one quick yank up and back down and do not hold the other end. Standing waves appear to stand in one spot and wiggle back and forth. These waves are the result of the interference of traveling waves. Fix one end of the slinky and move the other end up and down in a continuous pattern.*]

5. What is spacetime from Einstein's theory of general relativity? [*A rubber sheet can be helpful in demonstrating how spacetime warps. If you don't have a rubber sheet, use plastic wrap and stretch it out with help from one or two students. Note that real spacetime includes three dimensions of space joined with the fourth dimension of time, but this simple model shows only two spatial dimensions because nobody makes four-dimensional plastic wrap.*]

6. What are gravitational waves? [*Waves in the fabric of spacetime itself, like waves on the stretched rubber sheet or plastic wrap.*]

7. How are mass and gravity related to spacetime? [*Massive objects warp spacetime; place a tennis ball or baseball on the stretched sheet of rubber or plastic wrap. Warped spacetime is felt by objects as gravity; roll a marble into the area warped by the ball. Since this model is only a two-dimensional sheet, it only shows how mass warps two dimensions of space, but mass similarly warps the third dimension of space plus time as well.*]

Extension Prompts:

8. What are sound waves? Define electromagnetic waves or light. [*Sounds waves are longitudinal waves of air (or another substance) being alternately compressed and stretched. Light travels in transverse waves of wiggling electric and magnetic fields.*]

9. How can two light waves (or two waves of some other type) interfere with each other? [*Stretch two Slinky toys across the front of the classroom parallel to each other, reasonably close but not so close that they will get tangled together. If both are always wiggling up at the same places and times, and both are always wiggling down at the same places and times, the two waves can add together to effectively make a bigger wave. Students will have to imagine the combination of the two Slinky waves. If one Slinky is wiggling up at the places and times that the other is wiggling down, the two waves can effectively cancel each other out. Note that the two waves must have exactly the same frequency and wavelength in order to completely cancel each other out.*]

Physical Sciences Question Bank:

What are the major properties of a wave?

What is the difference between transverse and longitudinal waves?

What is the polarization of a transverse wave?

What is the difference between traveling and standing waves?

What is spacetime from Einstein's theory of general relativity?

What are gravitational waves?

How are mass and gravity related to spacetime?

What are sound waves? Define electromagnetic waves or light?

How can two light waves interfere with each other?

EARTH-SPACE SCIENCES

Discussion Questions:

1. What cosmic events could produce very strong gravitational waves? [*Black holes closely orbiting each other or colliding, neutron stars closely orbiting each other or colliding, stars exploding, the Big Bang and so on.*]

Extension Prompts:

2. How can scientists tell what sort of event gravitational waves are emanating from? [*Mathematical and computer models of different wave sources can show that different types of events generate characteristic gravitational waves with different frequencies and other properties. If the direction of the waves can be determined using three or more gravitational wave detectors, telescopes might detect electromagnetic waves from the same source.*]

3. Could gravitational waves help us learn more about dark matter? Explain. [*They might. If dark matter exists in dense enough "clumps," it could be detected by LIGO when it accelerates. However, scientists don't believe that dark matter resides in clumps dense enough to produce detectable gravitational waves.*]

Earth-Space Sciences Question Bank:

What cosmic events could produce very strong gravitational waves?

How can scientists tell what sort of event gravitational waves are from?

Could gravitational waves help us learn more about dark matter? Explain.

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion Questions:

1. How would you design a simple detector for vibrations (ground vibrations or loud sound waves)? [*Students may spontaneously think along the lines of the optical vibrometer shown later in this guide, or they may think of pens that scribble on paper in response to vibrations, or they may have other ideas.*]

2. How does a laser interferometer work? [*A laser beam (all at one wavelength/frequency) is split in half. The two beam halves travel different paths and then recombine. Small differences in the path lengths traveled by the two halves can make the two beams interfere with each other in different ways. When the two beams completely destructively interfere, the light will not be seen (it will be dark). When there is only constructive interference or a mix of both constructive and destructive, differing light patterns will be seen.*]

3. How does a detector for gravitational waves work? [*A large laser interferometer (miles in length) can detect even the very small compressions and expansions of empty space caused by gravitational waves.*]

Extension Prompts:

4. What are some other possible applications of laser interferometers? [*Student responses may vary, but may include measuring the optical flatness of mirrors or measuring small changes in the atmosphere through which one of the beam halves passes.*]

5. How can scientists tell that their gravitational wave detector is really detecting a gravitational wave, and not an earthquake, a passing truck or a frog burping in Toledo? [*LIGO detectors in both Washington state and Louisiana detected nearly identical signals, so it was not local. The signal arrived at the two detectors at almost the same time, indicating that the signal was traveling at the speed of light (as gravitational waves would) and was not more slowly moving waves from an earthquake. LIGO also filters out unwanted frequencies and uses additional monitors to detect other unrelated disturbances.*]

6. Using Blackline Master 4, examine the graph from "Physicists detect gravitational waves," showing the LIGO signals. Two black holes orbiting each other should produce two gravitational wave peaks per complete orbit — one peak from the first black hole when it passes slightly closer to Earth and the next peak from the second black hole when it passes slightly closer to Earth. Use the graph key and labels, and a ruler as necessary, to answer the following questions.

   a. Based on the predicted gravitational wave peaks, what is the slowest orbit (longest orbital period/lowest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period. [*Approximately 0.06 seconds or 17 orbits/sec near the left side of the graph.*]

   b. Based on the predicted gravitational wave peaks, what is the fastest orbit (shortest orbital period /highest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period. [*Approximately 0.013 seconds or 75 orbits/sec near the right side of the graph.*]

Engineering and Experimental Design Question Bank:

How would you design a simple detector for vibrations (ground vibrations or loud sound waves)?

How does a detector for gravitational waves work?

What are some other possible applications of laser interferometers?

How can scientists tell that their gravitational wave detector is really detecting a gravitational wave, and not an earthquake, a passing truck or a frog burping in Toledo?

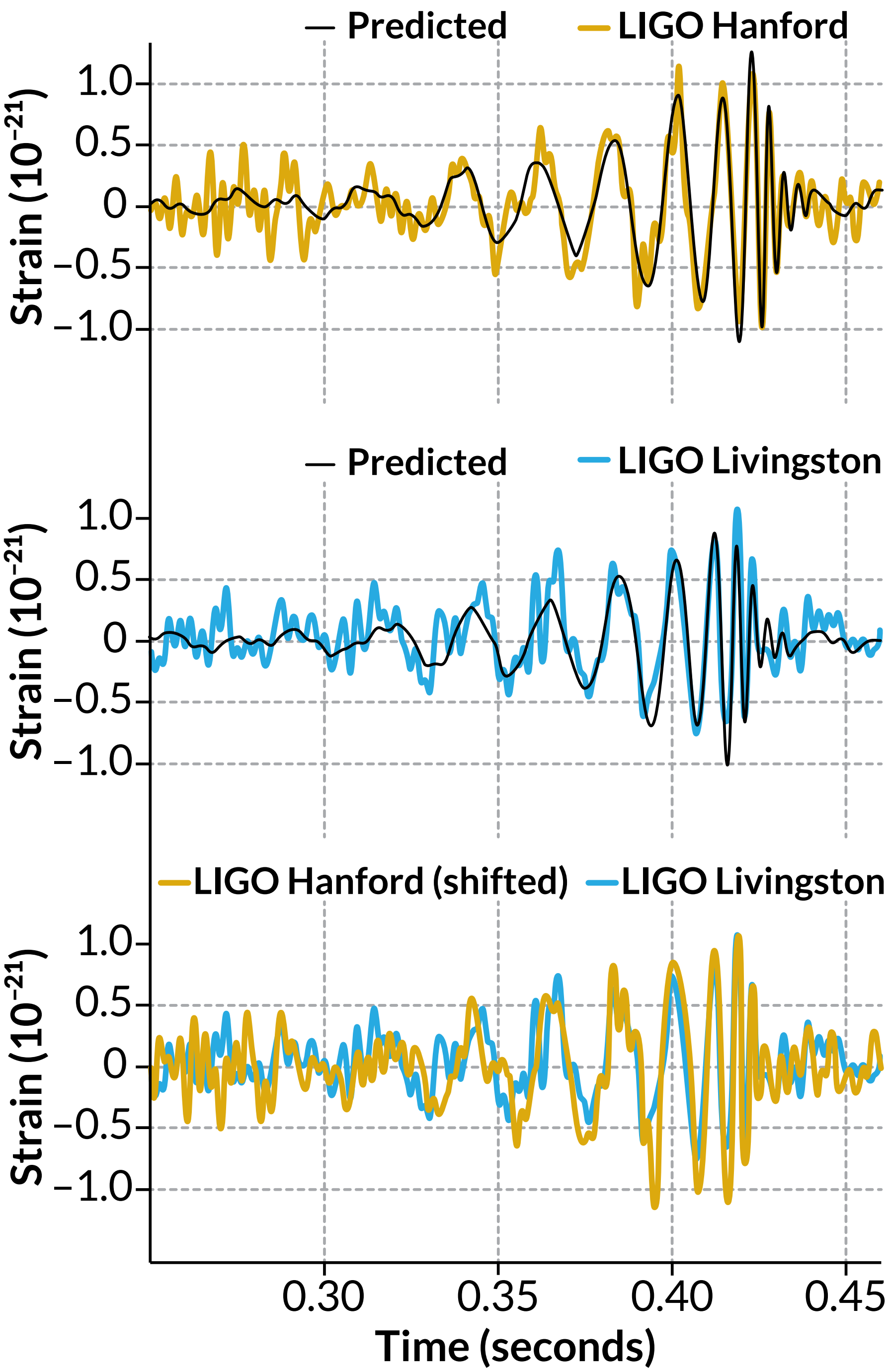
Based on the predicted gravitational wave peaks, what is the slowest orbit (longest orbital period/lowest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period.

Based on the predicted gravitational wave peaks, what is the fastest orbit (shortest orbital period /highest orbital frequency) you can find between 0.30 and 0.425 seconds? Approximate the time between consecutive gravitational wave peaks and multiply by 2 to get the orbital period.

Making Waves

Cross-Curricular Discussion

Directions: Use this graph from "Physicists detect gravitational waves" to answer the related discussion questions assigned by your teacher.



Wave Generation Activity: Teacher Guide

Class time: Approximately 30 to 60 minutes

Purpose: This activity uses water waves to model how gravitational waves are created and behave, and also how two light waves can interfere with each other.

Notes to the teacher: Waves on the surface of water in a clear container are most easily visible if the container is on an old-fashioned overhead transparency projector that is focused on a screen, so the ripples show up on the screen. If you only have one projector or none, students can still see the waves by setting the clear container on a dark surface and shining a flashlight at an angle at the water's surface. If you have an ELMO projector, use it to illuminate the water's surface and project the waves. The related activity "Dropping in with Gravitational Waves" by NASA's Jet Propulsion Laboratory can be used for additional background information.

Use Blackline Master 5 to help guide your students though the wave exploration.

Materials:

- Overhead transparency projector(s), ELMO projector or flashlights (in lieu of projectors and screens if those are not available)
- If using a projector: projection screens or blank walls, whiteboards or white poster boards on which to project
- Shallow clear glass baking dishes or clear plastic containers with flat bottoms (as large as possible)
- Water from a classroom sink, pitchers or beakers
- Marbles (or other small objects) to drop into the water
- Corks, Ping-Pong balls or other small objects to float in water
- Pencils
- Tape
- Stiff rulers
- Small binder clips or large paper clips
- Tuning forks (if available)
- Optional: students' cellphones to make video recordings of the ripples

Directions:

1. Help the students fill the clear containers about halfway full with water and visualize the water's surface by projecting it on a screen or by shining a flashlight across the surface.
2. Explain that waves produced on the water's surface can be a model for exploring the production of

ripples in spacetime. Explain to your students that water does not bend with gravity, as spacetime does, rather water is displaced by objects set on its surface. This model is best used for conceptualizing wave generation and interference.

3. Explain that objects disrupting the water's surface can generate waves, just as masses disrupting spacetime can generate gravitational waves.
4. Help the students understand that objects that are just sitting there create alterations in the surface (spacetime) but no ripples (gravitational waves in spacetime).
5. Guide the students to understand that objects must move around in the right ways to create ripples or gravitational waves. In this simple model, any motion will generate ripples. Under general relativity, acceleration or deceleration of a massive object is required to produce gravitational waves.
6. Let the students try many different ways of creating ripples, as outlined in Blackline Master 5. Have students observe the effects of each.
7. Help the students understand how water waves affect the relative positions of two corks or Ping-Pong balls floating on the water. (In this model, the water's surface moves and the objects will bob up and down as a wave passes.) How does this compare and contrast with how objects will move as gravitational waves pass by in spacetime. (In general relativity, the empty space between two objects can slightly expand and contract, even if the two objects stayed right where they were the entire time. See the earth oscillating in the Stephen Colbert and Brian Greene video.)
8. Guide the students to understand that the water ripples are analogous to light waves, and that two water waves can interfere with each other just as two light waves can interfere with each other. Two water waves can produce constructive and destructive interference patterns, just as two light waves can produce interference patterns in a laser interferometer.
9. When finished, have the students carefully pour the water down a sink or into containers and dry everything off.

SN
IN HIGH SCHOOLS
Dec. 24, 2016 & Jan. 7, 2017

Making Waves

Wave Generation Activity: Student Guide

1. Fill a shallow clear tank about half full with water.
2. Listen to your teacher for instructions on how you should illuminate the water so that you are able to see ripples on its surface.
3. Add a small object that floats on the water or breaks the surface of the water.
4. Define spacetime. In what ways is this a good model for spacetime?
5. What aspects of spacetime does this system not model accurately?
6. Does a stationary object generate water ripples? Does a stationary black hole create gravitational waves?
7. Describe the waves produced by a sudden event, such as a marble dropping into the water or a star exploding in space.
8. If you have a cellphone, you might use it to record video of the waves and play back the video in slow motion.
9. How do ripples affect the relative positions of two corks or Ping-Pong balls floating on the water? Compare and contrast the affect from water waves with the affect from gravitational waves in spacetime.
10. Tape three pencils together side-by-side, such that the two outer pencils stick up by the same amount and higher than the pencil in the middle. Your pencil contraption should look like a two-pronged fork.
11. Hold your pencil contraption vertically so that the outer two pencils stick down into the water and the middle pencil is not in the water. Rotate the contraption so that the outer two pencils circle each other in the water, like an eggbeater or like the two orbiting black holes in the video. Find a method that gives good rotary motion while minimizing side-to-side motion in the water. (The two outer pencil "black holes" should just orbit each other, not drift off or jitter around.)
12. Describe the waves produced by the two outer pencil "black holes" as they orbit each other at various speeds.
13. If you have a tuning fork, bang the two prongs against a table edge, or hit them with a pencil. What do the two prongs do?
14. Bang the tuning fork's prongs and stick just the tips of the prongs in the water. Describe the waves produced.

15. Do the waves from one tuning fork prong interfere with the waves from the other prong?
16. How is that similar to or different from the interference between two light waves in a laser interferometer gravitational-wave detector?
17. Lay a ruler on the end of the water tank such that half the ruler sticks out over the water like a diving board or pirate plank. Now give the end of the ruler two “snake fangs” that stick down into the water. Two small binder clips work well, with both clipped to the end of the ruler and one metal arm of each binder clip sticking down into the water. Alternatively, you could bend two large regular paper clips and attach or tape them to the end of the ruler.
18. Hold the ruler on the edge of the water tank like a diving board, gently lift the end over the water with your finger (don’t poke yourself with a paper clip), and let the ruler oscillate.
19. Describe the waves produced by the ruler with two “fangs.”
20. Describe the waves produced by the ruler if it only has one “fang.”
21. When the ruler has two fangs, do the waves from one fang interfere with the waves from the other fang?
22. What have you learned about gravitational waves from this experiment?
23. What have you learned about interferometers from this experiment?

Wave Detection Activity: Teacher Guide

Class time: Approximately 30 to 60 minutes

Purpose: In this activity, students will design, build, test and optimize a simple optical seismometer, as an analogy for a gravitational-wave detector.

Notes to the teacher: If you have plenty of time, this is a great opportunity for the students to have the freedom to create their own designs using a variety of materials and techniques with minimal guidance. If you have less time, you can guide the students toward specific design choices. For additional background information, explore this Physics Central page on Gravitational Waves from the American Physical Society.

Use Blackline Master 6 to help guide your students through the wave detection exploration.

Materials:

- Stationary stands from which to hang a pendulum. Ring stands with a protruding arm, burette clamp or ring are ideal. Music stands will also work. If necessary, pendulums could hang from camera tripods, stools, chairs or so on.
- String to hang a pendulum. If you would like to give your students more options and more time, you could also provide wires of varying stiffness, ranging from electromagnet wire to coat hanger wire.
- Scissors and/or wire cutters to cut the string or wire.
- Flat mirrors. Small classroom optical mirrors or makeup mirrors are ideal. Alternatives are anything that is very flat and very shiny. Shiny butter knives work well, as do shiny pie servers. If necessary, students could wrap aluminum foil shiny-side-out around a small piece of flat cardboard.
- Weights to weigh down the mirror as a pendulum. Metal washers, fishing weights or pennies work well.
- Small plastic bags (Ziploc snack bags, for example) to contain the weights.
- Tape. Blue painter's tape is by far the easiest to get off mirrors and silverware, but Scotch or masking tape could be used if necessary. Duct tape will leave a lot of sticky residue.
- Flashlights with a tightly focused beam. Many newer LED flashlights can be focused down to a very tight beam. Red laser pointers are also a possibility, but ensure that the students never accidentally or intentionally shine the pointer or its reflection in their or someone else's eyes. Green laser pointers are much too bright and should not be used.
- Books, small boxes or other props to position the flashlights.
- Light-colored screens, wall, poster boards or sheets on which the light can shine.
- Rulers
- Optional: students' cellphones to make video recordings of the output light signal
- Optional: clear glass or plastic sheets to shield the pendulum from air currents

Directions:

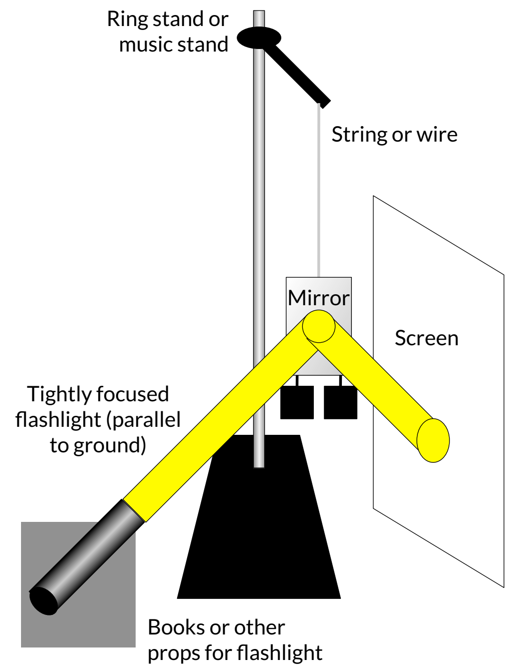
1. Students should set up the mirror as a pendulum, with the mirror approximately vertical and hanging by a string or wire from the stand (a diagram has been included in the student guide).
2. Students should set the flashlight on its side on books or other props, so that its tightly focused beam bounces off the mirror (at some angle) and hits the screen.
3. After everything settles down, the pendulum should be essentially motionless, and the light beam should essentially stay in one spot on the screen.
4. Help the students realize that small vibrations in the classroom can create small motions of the mirror, which can produce much larger and more easily detected changes in the position of the light beam on the screen.
5. Allow the students to optimize their designs to make them more or less sensitive to vibrations, for example by adjusting the length or stiffness of the string/wire, attaching weights to the hanging mirror, adjusting the angle and path length of the light beam and so on. Use the Engineering Design Process protocol by Advancement Courses for additional design support.
6. Discuss how to make the designs as sensitive as possible to vibrations of interest (such as talking close to the mirror or a light tap on the table) and how to make them as resistant as possible to other stimuli such as air currents.
7. Discuss the similarities and differences between the students' designs and a laser interferometer for detecting gravitational waves. [*In both systems, a very small wave can cause a much larger and more easily detected change in a light beam. In the students' system, there is one beam of light containing many different wavelengths, and it indicates wave vibrations by changing its position on the screen. In the LIGO gravitational wave detectors, there are two beams of laser light at the exact same wavelength, and they indicate gravitational waves when they interfere with each other in certain ways.*]

SN
IN HIGH SCHOOLS

Dec. 24, 2016 & Jan. 7, 2017 Making Waves

Wave Detection Activity: Student Guide

1. Set up a ring stand or music stand with an arm or surface sticking out at the top.
2. Tape or tie a string to the arm or surface sticking out at the top of the stand. Tape the bottom of the string to a mirror such that the mirror hangs vertically and is near the table surface but does not drag on the surface.
3. Make a flashlight beam as narrowly focused as possible. Put the flashlight on its side (on books or other props) such that the beam bounces off the mirror at an angle and then shines on a screen, board or white sheet.



4. Using the ruler, approximately how many millimeters does the mirror move from small vibrations, such as a tap on the table?
5. Using the ruler, approximately how far does the light beam on the screen move due to those mirror vibrations?
6. If you have a cellphone, you can use it to make videos of the motions of the mirror and/or light on the screen and play them back in slow motion.
7. Why is the light beam useful for measuring small vibrations?
8. Let the mirror come to a complete rest. Tap the table more lightly than you did the first time, can your system detect that? How sensitive is it?
9. Let the mirror come to a complete rest. If you stomp on the floor, can your system detect that? How sensitive is it?
10. Let the mirror come to a complete rest. If you talk at the mirror at close range, can your system detect that? How sensitive is it?
11. What sorts of vibrations would you like your system to detect?
12. What sorts of stimuli would you like your system not to detect?
13. How can you make your system as sensitive as possible to what you want it to detect, and as resistant as possible to other stimuli? You can:
    - Choose the surface on which your system sits
    - Adjust the length of the string

- Use wires of varying stiffness instead of string
- Try other types of mirrors
- Tape weights to your mirror
- Adjust the angles of the light beam
- Adjust the path lengths of the light beam
- Adjust the surroundings around your system
- Choose something else to modify

14. Explain your design:
15. Explain how well it worked on your selected stimuli:
16. How is your system similar to a gravitational wave detector?
17. How is your system different from a gravitational wave detector?