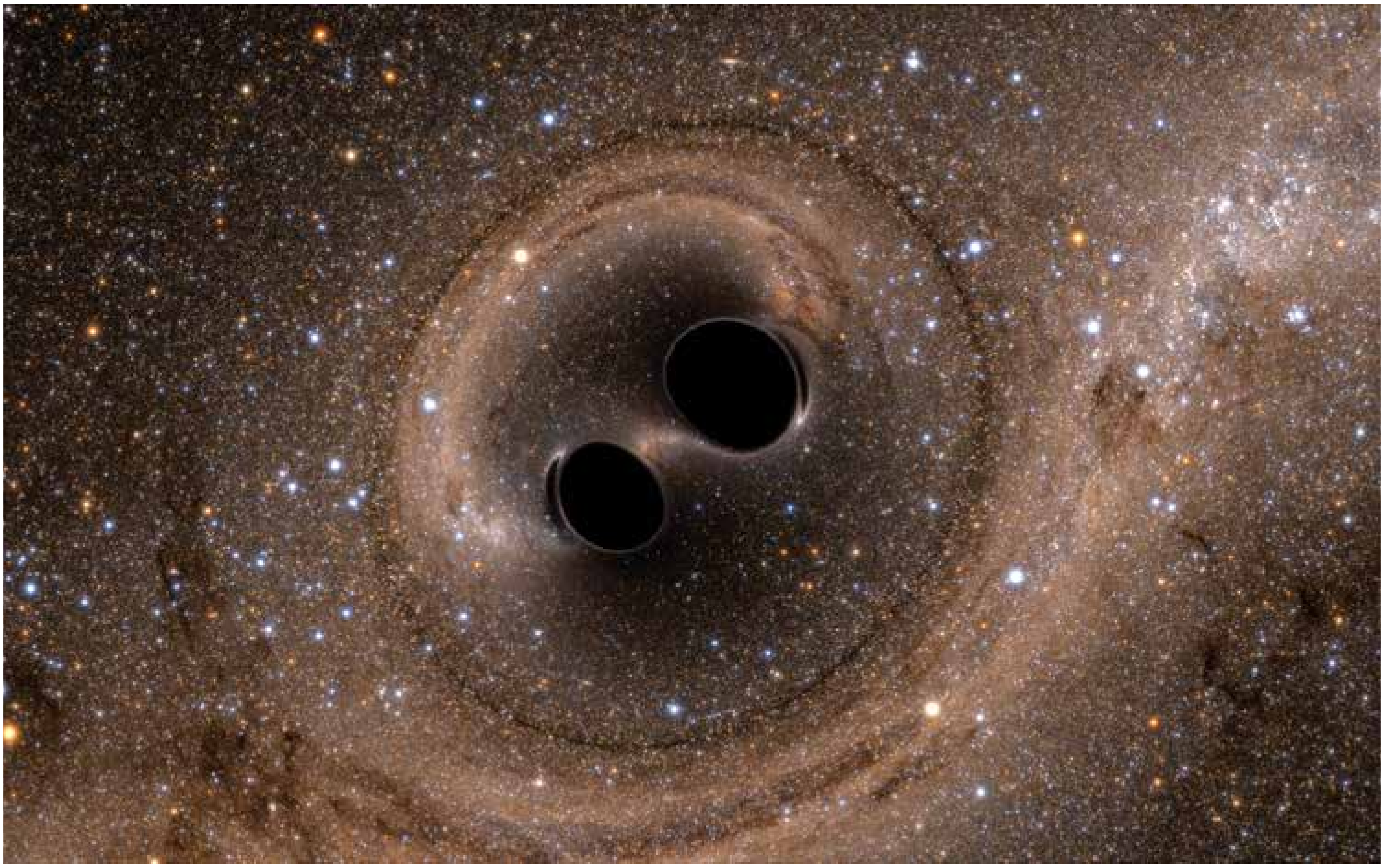
Science News
IN HIGH SCHOOLS | EDUCATOR GUIDE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Physicists detect GRAVITATIONAL WAVES

SOCIETY FOR SCIENCE & THE PUBLIC

SN EDUCATOR GUIDE

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About the Guide

The *Science News* article "Physicists detect gravitational waves" reports the groundbreaking discovery of gravitational waves, which are a major prediction of Einstein's general theory of relativity and open a new window on the cosmos.

"Physicists detect gravitational waves" can be used across a wide range of curricula, with a focus on **astronomy** and **physics**. The activities, questions and discussions in this educator guide can be used to support the following education standards:

Next Generation Science	Common Core
Energy: HS-PS3-2	ELA Standards: Reading: Informational Text (RI): 1, 2, 3, 4
Waves and their Applications in Technologies for Information Transfer: HS-PS4-1, HS-PS4-5	ELA Standards: Writing (W): 8, 9
Earth's Place in the Universe: HS-ESS1-2	ELA Standards: Speaking and Listening (SL): 1, 2, 3, 4
	ELA Standards: Language (L): 1, 3, 4
	ELA Standards: Reading for Literacy in History/Social Studies (RH): 1
	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 6, 7, 8, 9
	ELA Standards: Writing Literacy in History/Social Studies, Science and Technical Subjects (WHST): 1, 2, 9

Prior to reading

Guide student reading by pointing out connections between this article and what students are learning in class. Here, find ideas for standard-aligned paths to follow while reading:

- Ask students what they know about the characteristics of waves. Do they know the different types of waves (*mechanical versus electromagnetic, transverse versus longitudinal*) and the parts (*peak/crest and trough*) and characteristics (*frequency, amplitude, wavelength and propagation direction*)? Teachers can use a Slinky to model mechanical waves by holding one end steady and moving the other end up and down (*transverse waves*) or pulsing it in and out (*longitudinal waves*). Students can draw examples of waves with low to high amplitudes, frequencies and wavelengths.
- Ask students if they know how seismometers work to measure the magnitude and location of an earthquake. Incorporated Research Institutions for Seismology has a nice fact sheet on seismometers, and Michigan Tech has an educational site describing how to locate an earthquake's epicenter. Focus on the use of multiple instruments positioned in different locations. Ask students how a seismometer tells the difference between a car that rumbles down a street and an earthquake occurring. Students might mention the strength of the signal, and might also know that multiple seismometers positioned far apart wouldn't all pick up a local rumble.
- Ask students what they know about black holes. They might have heard of them from science fiction movies or books. Make sure your students know that black holes are real astrophysical phenomena, lurking at the center of our galaxy and throughout the universe.

After reading: Comprehend

You can adapt and print these questions (Blackline Master 1) to check for comprehension and analysis before or after discussion:

1. **What is the main topic of the article?** *(Gravitational waves have finally been detected through direct measurement, a further confirmation of Einstein's general theory of relativity.)*
2. **Why does this discovery change the future of space research?** *(Scientists now have a new way to collect evidence about the universe's past. New observatories will look for more of these extreme events and could lead to many more discoveries and a deeper overall understanding of the nature of the cosmos.)*
3. **What is a gravitational wave, sometimes abbreviated as gravity wave?** *(Students might say: vibrations of spacetime, ripples in spacetime, waves in spacetime, energy that travels through spacetime and so on.)*
4. **How does the Laser Interferometer Gravitational-Wave Observatory detect gravitational waves?** *(The detector splits a laser beam and sends the resulting beams up and down two intersecting tubes. By looking for a light signal produced when the beams recombine, and studying the nature of that signal, researchers can know whether gravitational waves have squeezed and stretched the arms.)*

5. **Why are multiple detectors needed?** *(To be sure that the signal is not local and to help identify the source of the disturbance.)*

After reading: Analyze

1. **After reading the article, what can you infer about Einstein's theory of general relativity?** *(Answers will vary but might include: Einstein's theory changed the way people think about the universe. The theory says there is not an invisible force pulling objects together. Instead, space and time are united in spacetime. Massive objects warp this spacetime. More massive objects warp spacetime more than less massive objects. Indentations in spacetime explain the concept of gravity. General relativity makes predictions about how different objects in the universe behave. Many of the theory's predictions have proven true. General relativity predicts extreme, massive and powerful events and collisions. These events leave signatures that can travel across the universe.)*

2. **What are the advantages and disadvantages of building gravitational wave detectors on land? What about in space?** *(Gravitational wave detectors have to be large and complex. Positioning them on land saves on the cost and difficulty of launching them into space. On land, they are also easily accessible, so they can be upgraded or fixed if there are problems. But land detectors are sensitive to rumbling trucks and other Earth activities, making it harder to pick out a faint signal. When the eLISA mission launches, the space-based detector will hear gravitational waves with frequencies under 1 hertz, compared to LIGO's tens of hertz to several thousand.)*

3. **Do you believe that detecting gravitational waves was a "scientific moonshot," as David Reitze says at the end of the story? Why or why not?** *(Students can agree or disagree with David Reitze, but they should defend their answer. Those who think it is a scientific moonshot might point to the fact that making gravitational wave detection possible required dramatic technological developments. Scientists were working on this problem for decades, and it required building a huge and expensive detector, along with the collaboration of many scientists. Students might say that detecting waves at this distance was unimaginable at the time of Einstein. Students might also realize that building these detectors was risky, because scientists couldn't be sure the waves would be detected. Those who think it is not a scientific moonshot might point to the fact that scientists knew these waves existed so it was only a matter of time before they were detected. Students might also point out that, unlike for landing on the moon, there was no risk to human survival in this case. Also, the new finding relates more to studying the universe than visiting new territory, and so on.)*

Discuss and Assess

After students read the article independently, return as a group to the concepts outlined prior to reading. Invite students to share their answers and observations from the article and lead a class discussion that further underscores your current curriculum. The discussion can serve as an informal assessment. Ideas for further reading discussion or writing prompts include:

- This article (as well as the accompanying feature article, "Listening for Gravity Waves," page 24) says that the discovery is worthy of a Nobel Prize. But Nobels are traditionally shared by no more than three people, and this detection was the work of a vast number of scientists collaborating over time. Ask the students what types of expertise were necessary to make this project possible. *(Theorists such as Einstein; experimentalists who could figure out how to build the machine; team managers; people with expertise in interferometers and lasers, as well as mirrors and light detectors; construction teams; data and statistical analysts; people who could communicate the aims of the project to the NSF and other funders, as well as the general public.)* In what way was this a collaborative effort? Who had to buy in? Who had the most to lose? Who ultimately paid for the effort? Who do students think might receive the Nobel Prize? Who do they think should receive it?

- You can also use this discussion as an opportunity to introduce the idea of big science. How might this discovery be used in an argument for Congressional spending on big science? What big projects have been publicly funded in the past? What are the benefits of those kind of projects? *(Encourage students to think not only about technological applications, but also about the value in pursuing knowledge for its own sake, the pride that comes from that pursuit, the value of public engagement and possible parallels with the benefits of art.)* Has the LIGO experiment already proved its worth? Why or why not? If not, what results or outcomes would change the students' minds?

- Distribute a copy of the "Cosmic shake-up" infographic, page 22. Individually or in teams, have students study the infographic and the information it provides. What questions does it answer? What does it leave out? How does it simplify information for the reader? Ask students to critique the infographic. What do they like and dislike about the infographic? How would they do it differently? What affect would their proposed changes have on readers? Ask students to consider not only content but also aesthetics. If time allows, you could lead a similar discussion about *Science News*' gravitational waves video: https://www.youtube.com/watch?v=HwC5IYw5uAE. How do the two presentations compare with one another? What is each trying to cover? Who is the target audience? What are the strengths and weaknesses of using print versus video? Which presentation is more successful? Why?

Extend

Offer students other ways to explore the content of the article as it relates to your curriculum, such as:

SPACETIME SHEET

The article discusses how gravitational waves warp the fabric of spacetime. To make the idea of spacetime more concrete for students, stretch a sheet of rubber across a frame and clamp it in place. Then place objects of different sizes and masses, one at a time, on the stretched rubber sheet. Students can predict how the sheet will deform. What happens if you put a second object on the sheet at the same time? Explain to students that though the rubber sheet might help them visualize spacetime, it is not a perfect model. There are behaviors of spacetime that cannot be easily captured by the model — the twisting of spacetime caused by a spinning object or the gravitational waves that spread outward when two objects collide, for example. Ask students to think of other problems with the model. (*The sheet, for example, doesn't convey how time is warped along with space, meaning time slows down close to a massive object.*)

WAYS OF SEEING

Physicist John Mather says that the gravitational wave discovery "opens up a new window into astronomy that we never had." Ask students to think about what he means by that statement. (*Until now, major missions have used primarily visible light waves and other electromagnetic waves, and sometimes particles, to learn about the universe. Gravity waves are a completely different type of signal.*) Through independent research, have students fill out Blackline Master 2 with "ways of seeing" the universe. An example is provided. Students can research the types of detectors that have studied each signal and their major discoveries.

INSTRUMENT ISOLATION

The Laser Interferometer Gravitational-Wave Observatory looks for ripples in spacetime by splitting a laser beam and bouncing the resulting beams back and forth between sets of mirrors before the beams recombine. To achieve utmost sensitivity, those mirrors have to be isolated from outside vibrations. In this activity, Blackline Master 3, students will model a simplified isolation system to understand how it works. As students work through the activity, encourage them to make predictions about what they can expect from their model system. This demonstration was inspired by Stephen Edberg, an astronomer at NASA's Jet Propulsion Laboratory.

ADVANCED EXTENSION

For more advanced classrooms, educators might want to have their students build a Michelson interferometer. There are many resources available online, including a glue approach and a magnet approach put together by LIGO, plus YouTube videos explaining the process.

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Comprehend

After reading the article "Physicists detect gravitational waves," answer these questions:

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

2. **Why does this discovery change the future of space research?**

3. **What is a gravitational wave, sometimes abbreviated as gravity wave?**

4. **How does the Laser Interferometer Gravitational-Wave Observatory detect gravitational waves?**

5. Why are multiple detectors needed?

Analyze

1. **After reading the article, what can you infer about Einstein's theory of general relativity?**

2. **What are the advantages and disadvantages of building gravitational wave detectors on land? What about in space?**

3. **Do you believe that detecting gravitational waves was a "scientific moonshot," as David Reitze says at the end of the story? Why or why not?**

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Ways of seeing

Directions: What are the different signals that researchers use to learn about the universe? What types of detectors do they use to study those signals? Use the graphic organizer below to track your research.

Type of signal	Types of detectors used	Example of a major discovery	Who made the discovery and when?
Visible light	Ground- and space-based telescopes	Discovery of Pluto	Clyde Tombaugh, 1930

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Instrument isolation

In order to shield the experiment from rumbles that aren't gravitational waves, LIGO was designed with highly advanced vibration isolation systems that consist of active and passive damping. The active damping devices sense ground movements and then perform counter movements to keep the instruments very still. The passive damping system uses a pendulum with four levels to suspend the mirrors and thus limit movement.

In this activity, you will build a model to demonstrate how a more simplified suspension system works.

Materials:

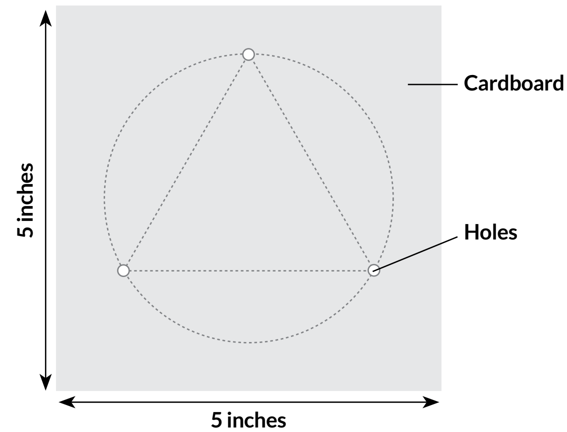
- cardboard or other stiff board
- protractor
- writing tools
- ruler
- punch or drill for making holes in board
- string
- 2-ounce paper or plastic cups for water

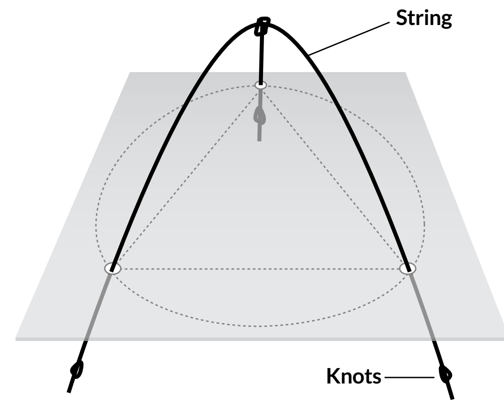
Build the platform:

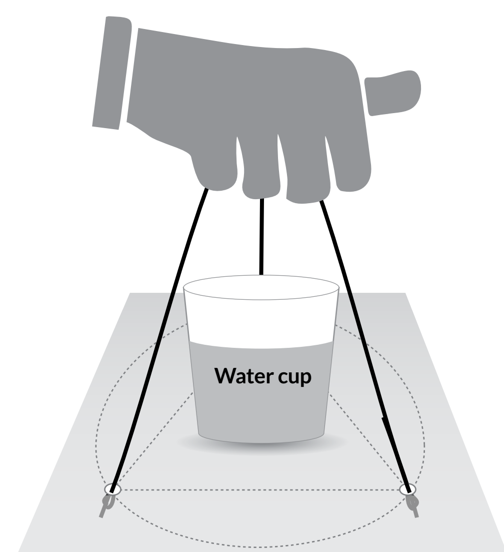
1. Cut a square piece of cardboard or other stiff board that measures 5 by 5 inches.
2. Mark the center of the square and three points spread 120-degrees apart on a circle of diameter 3.5 inches or greater. Your three points should form an equilateral triangle.
3. Punch or drill holes at each point of the triangle, large enough to push a piece of string through.
4. Cut a 1-meter length of string and put each of its ends through a hole in the platform, tying knots on the underside of the platform. This string should form an upside-down "U" shape.
5. Cut an additional piece of string and put it through the remaining hole, again knotting the end under the platform.
6. Knot the loose end of this string to the "U" string so that the strings can slide for proper adjustment.
7. The platform should hang horizontally when you lift by the strings. (Be sure you have space to fit a small cup on the platform without the strings touching the cup.)

Test the platform:

1. Place the cup on the platform and lift your system into the air.
2. Move your hand back and forth. What do you observe?
3. Invite a fellow classmate to hold a "vibration race."
4. Designate a start and finish line.
5. One of you will extend your arm and carry the platform with the cup on it, holding it from the strings. The other will extend his or her palm and set the cup on the palm.
6. Walk as quickly as possible to the finish line without spilling any of your water.







Answer these questions:

1. What made it to the finish line first without spilling water?

2. Why do you think that student was most successful?

3. How does the suspension system limit vibrations?

4. How might you add additional vibration isolation into the system? Draw a diagram of your ideas in the space below.