



Teachers Guide for *Einstein's Messengers*

This guide accompanies *Study Questions for Einstein's Messengers*.

Einstein's Messengers Learning Objectives for Students

The objectives below focus on the themes of *Einstein's Messengers* that relate to national science standards. You can learn more about the movie's relationship to standards by following the "Einstein's Messengers and National Science Standards" link on the movie Web site: www.einteinsmessengers.org.

- ◆ Recognize that important scientific ideas can change
- ◆ Contrast Einstein's model of gravity with Newton's
- ◆ Recognize the similarity between gravitational waves and other types of waves
- ◆ Recognize that interferometers are new tools in the search for gravitational waves
- ◆ Recognize that computers are essential in constructing models of star collisions and similar events
- ◆ Describe the size of the LIGO project in terms of numbers of scientists, engineers and students involved
- ◆ Describe the role of curiosity in the advancement of science

Short-answer Movie Questions for Students

Sample responses to the student questions appear below. The responses represent mainstream ideas from the movie. Students might generate a variety of insightful ideas in addition to these.

1. True or false: Humans have held the same basic idea of gravity for hundreds of years. Explain your choice. *In the movie: 2:40*

False. A major transition occurred as the framework of gravity associated with Newton's mathematics gave way to Einstein's general theory of relativity. *(Newton's gravity equation remains commonly taught and used today. Einstein's general theory of relativity provides accuracy in the circumstances where Newton's equation breaks down; very strong gravity and speeds that approach the speed of light. Einstein's theory also provides an overarching explanation of gravity that was missing in Newton's framework. Embedded in this explanation is the notion that space and time are not fixed. They can stretch or shrink. Einstein also meshed space and time into a single entity, space-time, that forms the fabric of the universe.)*

2. Describe Newton's concept of gravity. How did Einstein's ideas about gravity differ from Newton's? *In the movie: 2:50, 3:15 - 4:15*

The modern concept of gravity is Einstein's, that gravity is the curvature of space (actually space-time) that arises from the presence of mass. Prior to Einstein, Newton's

universal law of gravitation suggested that gravity is a force, a pull between two or more masses.

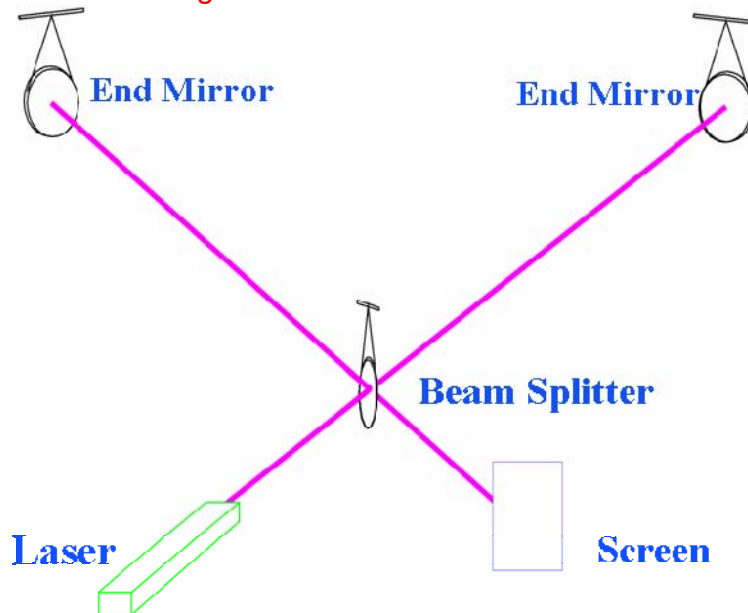
3. Describe a difference and a similarity between gravitational waves and water waves. *In the movie: 4:30 (sim), 4:48 (diff), 5:49 (sim)*

Difference: Water waves move through a material medium; they are vibrations of matter. Gravitational waves are vibrations of space and they exert only the tiniest of effects on the earth's matter. **Similarity:** Both types of waves are transverse. They oscillate perpendicular to their directions of travel. *(A floating object such as a stick acts as a wave sensor as it bobs up and down when the water wave passes by. LIGO's mirrors will act as markers of the space in which they rest, vibrating back and forth as gravitational waves pass by.)*

4. What is the name of the instrument that LIGO uses to detect gravitational waves? Draw a simple diagram of one of these instruments.

In the movie: 7:17 – 8:45

LIGO uses interferometers as gravitational wave detectors.



5. Why is technology important in LIGO? In your opinion, is LIGO a science project, an engineering project or both? Explain your choice.

In the movie: 9:35 – 11:10, 12:00 – 13:50

Students might provide a number of thoughtful responses. In LIGO, technology forms the bridge between the concept or goal of detecting gravitational waves and the act of making the detections. Einstein himself never expected that scientists would directly measure gravitational waves. The development of technology now makes such measurements possible. Science provides the theories that guide LIGO's research. Science also provides the framework for how LIGO uses interferometers to search for gravitational waves. The development, construction and reliable operation of the interferometers requires engineering of a quality that must match the quality of the science.

6. The movie shows a number of computer simulations (models) of events that happen in space. How will scientists decide if these models are accurate?

In the movie: 14:20 – 15:00

Scientific models are judged on their ability to provide accurate predictions. Models such as those in the movie allow scientists to predict the features of gravitational waves that various astrophysical events will produce. If these predictions match the data that detectors such as LIGO will collect, the models will be successful. Astrophysicists expect to be surprised by the information that gravitational waves will bring, and the models may change accordingly.

7. How many people work on LIGO, approximately? Why might such a large number of people be necessary? *In the movie: 10:48*

The movie states that the number of people working on LIGO is in the hundreds. Such a large number is necessary to support the operation of the Observatories, the analysis of detector data and the development of the theories that guide the work. *(The interferometers are very complex instruments with several subsystems. One group of LIGO personnel participates in the operation, maintenance and improvement of these detectors. Another group analyzes the data that the detectors produce. LIGO's interferometers collect over 6 Megabytes of data every second. The analysis of this volume of data requires many computers but, more importantly, many minds. A third group of scientists contribute to LIGO not by working with the detectors or their data but instead by studying the theories related to the astrophysical systems that LIGO targets. These scientists strive to develop stronger understandings of the expected frequencies of astrophysical events and the signals that these events will produce. The boundaries between these categories of work are soft. Many people in LIGO participate in more than one of these three activities.)*

8. Why is it important for a scientist to be curious? *In the movie: 17:00 – 17:30*

Curiosity is essential in basic research. If we do not ask questions about what the universe is like, and if we do not feel that the answers to these questions are vitally important, our understanding of the universe will stagnate. Curiosity is the fuel that propels basic research projects of all sizes. *(Motivations other than curiosity often play a role in applied research. The need to solve an environmental problem might drive one research program. Potential commercial benefits might drive another.)*

Open-ended questions

Teachers should expect significant diversity in the ideas that students present in response to these questions.

1. Many people think they know what a ‘typical’ scientist looks like (white lab coat, thick glasses, funny hair, etc.). Do you think that the LIGO scientists in the film fit this description? What, in your opinion, would be some important characteristics of scientists if not their appearance? What makes a scientist a scientist?

The movie shows a wide variety of individuals who work on LIGO. Students should be encouraged to consider and discuss this variety. Perhaps there is no single characteristic that “makes a scientist a scientist,” but one unifying trait might be habits of mind. Scientists share a method of thinking about problems that emphasizes the development of explanations that can be tested by making new observations or by devising new experiments.

2. Imagine that you are working for LIGO. You and your fellow scientists think that you have finally detected gravitational waves directly. No one has ever done this before. What would you do to build confidence in your result? How would you answer those who might say, “No, the signal you measured was probably a truck driving by, or an airplane flying overhead, or a small earthquake”?

LIGO operates two widely spaced observatory sites to distinguish local environmental effects from gravitational wave signals. A truck driving by the Washington site will not produce a signal at the Louisiana site, but a gravitational wave should appear at both locations. LIGO also operates a myriad of environmental sensors at each site. These sensors should register trucks, airplanes, earthquakes and other disturbances but they will not detect gravitational waves. These two confidence-building strategies are not failsafe. Certain environmental effects could register at both sites. In addition, an event such as an airplane flyover might produce a signal that is too weak to show up on an environmental sensor such as a seismometer, but the signal could show up at the level of the noise limit in a gravitational wave interferometer.

3. LIGO scientists work at institutions all over the world. Would you enjoy working with a group of hundreds of people that are spread out in this fashion? What would be some of the challenges of working with a group this large? What would be some of the potential benefits?

Student responses will vary. LIGO constantly faces the challenge of facilitating communication between very busy scientists who live in time zones across several continents. Project organization is also a challenge but is necessary to prevent duplication of effort. LIGO benefits greatly from the size of the LIGO Scientific

Collaboration, primarily since LIGO's research program requires many participants. Complex research problems exist throughout the project; progress on these problems occurs more quickly as more scientists participate.

4. LIGO's quest to measure gravitational waves is an example of basic science research. Basic research projects are designed to question, discover and explore nature's fundamental behaviors. Do you feel that basic science projects such as LIGO are important? Is there value in learning about the universe? Share your thoughts.

Student responses will vary. As our understanding of nature and of the universe improves, our ability to form theories that may be of broad benefit also improves. Quantum mechanics arose from basic research into the nature of light and matter; it is a theory that now regulates our understanding of devices as practical as lasers and transistors. Gravitational wave astronomy may not directly influence the development of technology in the way quantum mechanics has, but what gravitational waves teach us about matter and space-time may ultimately be of significant benefit. A scientist in *Einstein's Messengers* states that the search for gravitational waves requires "pushing the limits of technology in every sense," a process that results in better technology not only for LIGO but also for other research and commercial interests.