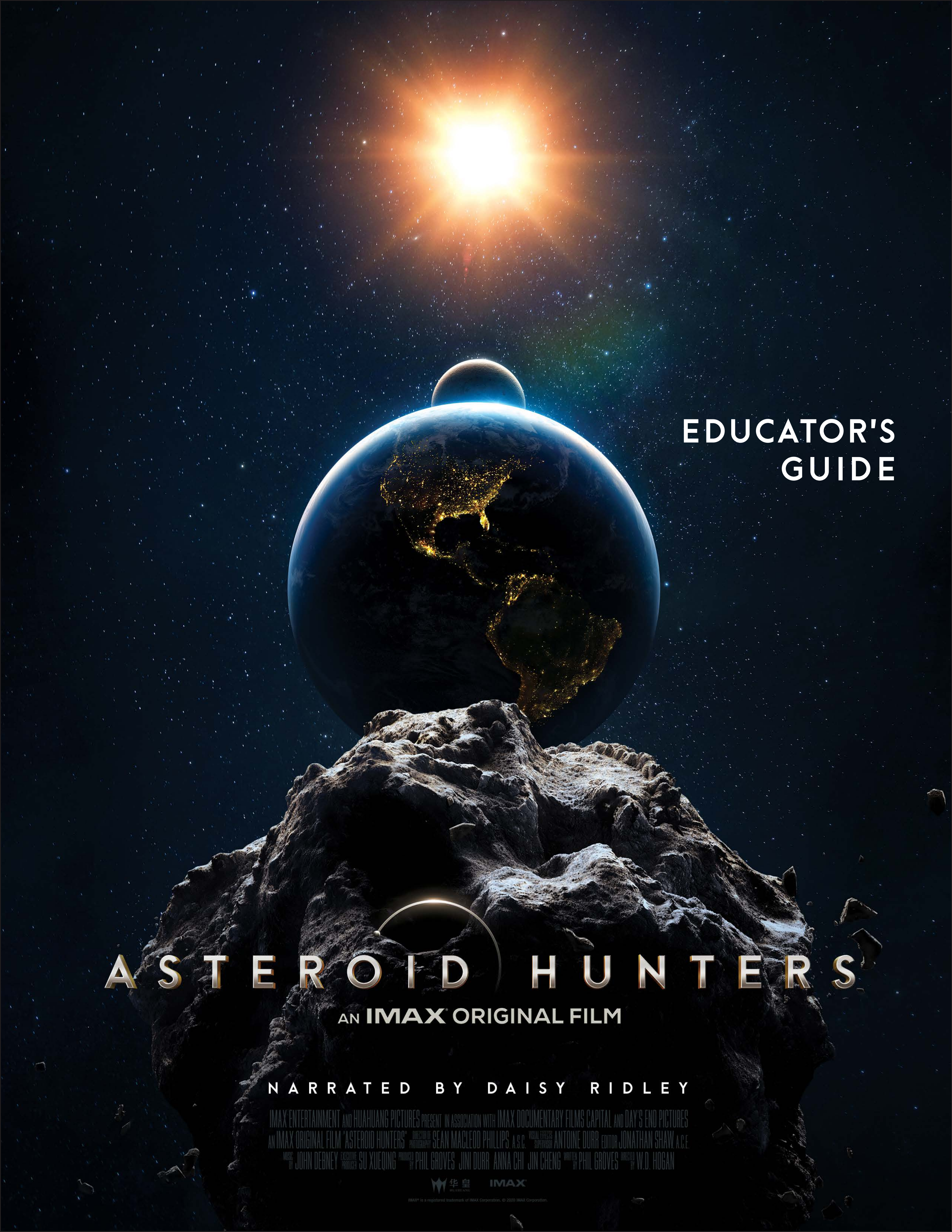
EDUCATOR'S GUIDE
ASTEROID HUNTERS
AN IMAX ORIGINAL FILM
NARRATED BY DAISY RIDLEY
IMAX ENTERTAINMENT AND HUAHUANG PICTURES PRESENT IN ASSOCIATION WITH IMAX DOCUMENTARY FILMS CAPITAL AND DAY'S END PICTURES
AN IMAX ORIGINAL FILM "ASTEROID HUNTERS" DIRECTOR OF PHOTOGRAPHY SEAN MACLEOD PHILLIPS, A.S.C. VISUAL EFFECTS SUPERVISOR ANTOINE DURR EDITOR JONATHAN SHAW, A.C.E.
MUSIC BY JOHN DEBNEY EXECUTIVE PRODUCER SU XUEQING PRODUCED BY PHIL GROVES JINI DURR ANNA CHI JIN CHENG WRITTEN BY PHIL GROVES DIRECTED BY W.D. HOGAN
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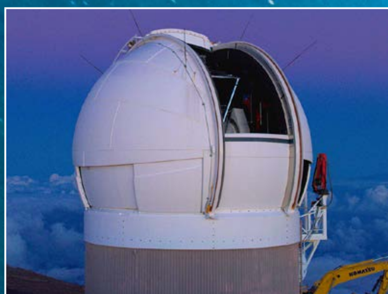



AN EXTRAORDINARY FIELD TRIP AND LEARNING EXPERIENCE!

Dear Educator,

Planetary defense is a relatively new science. Only a few decades ago did we become certain Earth's history of asteroid impacts was sure to repeat itself. Could we save our world today from a cosmic threat? You bet we can. But to tend to this problem, we must first understand it. That's where ***Asteroid Hunters*** comes in.

Asteroid Hunters will take your students on an exciting field trip across the Solar System and to the dawn of time. They'll watch how gravity spun gas and dust into our Solar System, how rocky debris gathered into worlds, and how the planet-building leftovers became asteroids. They'll learn that these natural wonders of deep space brought water to planets, and the building blocks of life itself. They will also see how we possess the technological know-how to keep an asteroid from hitting our planet–unlike the doomed dinosaurs of 65 million years ago.

Your students will have a front row seat to a hypothetical asteroid impact as never before seen! ***Asteroid Hunters*** is the first movie to portray this rare phenomenon as it would actually happen. They will witness world-saving technologies that arise from the imaginations of scientists. They will receive insight into how governments would respond to an asteroid threat, evacuating hundreds of square miles to protect lives.

Combined with an unforgettable viewing of ***Asteroid Hunters***, this Educator's Guide will make a lasting impression on your students. Their imaginations fired up by how science can save Earth, your students may choose an educational path that will allow them to contribute to the future protection of Earth's fragile environment. On the pages that follow, a variety of hands-on activities and exercises will augment your curricula for astronomy, technology, engineering, mathematics, social studies, and the arts.

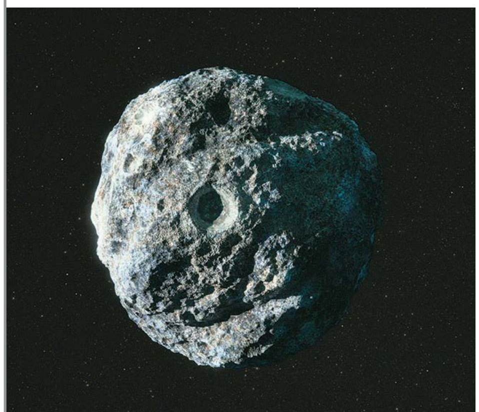
Understanding how our global community and a rare cosmic phenomenon may one day intersect, your students will learn how working together is the only way we can protect our world.

Best regards,

Dr. Donald K. Yeomans
NASA/JPL Senior Research Scientist, retired

ASTEROID HUNTERS
AN IMAX ORIGINAL FILM

ASTEROIDS IN ORBIT

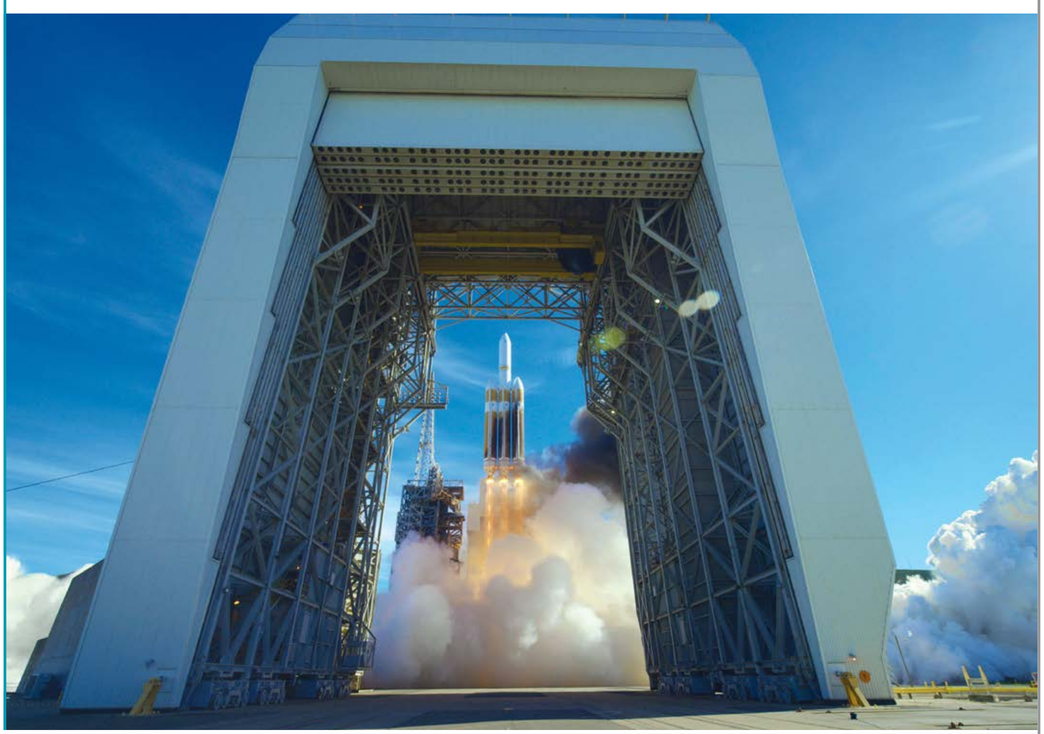


Boost your STEAM curriculum for grades 3-5 by using the new IMAX experience, ***Asteroid Hunters***, as a launch pad for teaching about force, energy, and the Solar System. Students will learn about the origins of our planets and current asteroid-defense research by NASA and international partners. Set the stage for your learning adventure with the hands-on activity on pages 5-6. Photocopy these pages to provide every student with a pair of activity sheets. (Follow your school's safety rules for all experiments.) For standards correlation, see page 19.

Answers:

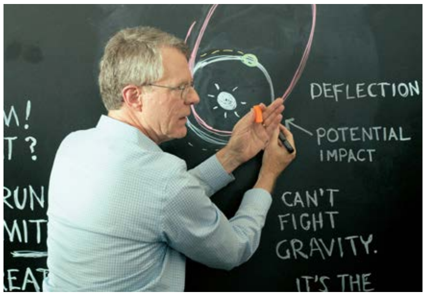
Part 1: Students should note that when they try to walk forwards and backwards (perpendicular to the rope), they are pulled towards the post. The rope represents the Sun's gravity pulling the planets towards it, and the person's perpendicular walk is the planet's inertia. *Bonus:* Answers may vary. Scientists believe that gravity from Jupiter prevented the asteroids in the belt from forming into a planet.

Part 2: Students should note that kinetic energy is in moving objects. When a moving object collides with another object, it changes the speed and direction of the second object.



ASTEROIDS IN ORBIT

In an exciting new IMAX experience, ***Asteroid Hunters***, space will feel closer than ever imagined. Travel around the Solar System to discover how our planet formed and get close to the dangers in orbit around us. Watch as fictional asteroid Ficta A3D speeds towards Earth, and meet the teams of scientists and engineers trying to stop it.



PART 1 UNDERSTANDING GRAVITY

Did you know that there are hundreds of thousands of rocky, airless worlds called *asteroids* orbiting the Sun along with our Earth? Some asteroids are as small as pebbles, while others are as big as mountains. Most asteroids orbit in the space between Mars and Jupiter, but they can be found throughout the Solar System. How do they stay in orbit? How does Earth stay in orbit? Let's head out to the schoolyard and try an experiment to find out. (Follow your school's safety rules for all experiments.)

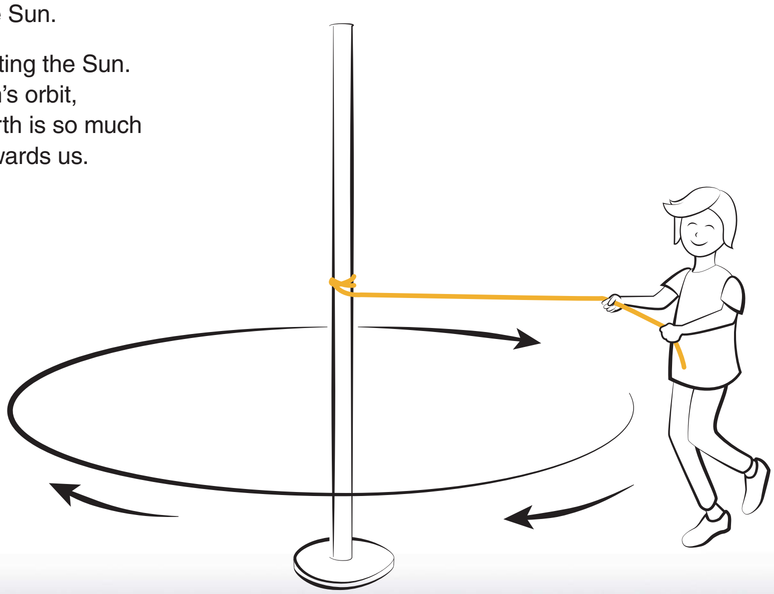
1. You will need a long rope, like a jump rope or sturdy twine.
2. Tie the rope around a sturdy pole. The pole will act as the Sun. If no pole is available, have one classmate stand in the center of an open area and hold one end of the rope.
3. Take turns with your classmates holding the other end of the rope. Walk as fast as you can perpendicular to the rope, pulling away from the pole as you go to create an orbit.

Observations: Use the back of this sheet to take notes. Think about what happens when you try to walk towards the pole, away from it, and perpendicular to the rope. Which part of this experiment represents the force of the Sun's gravity on the planets?

What's happening here? In our Solar System, the Sun pulls everything towards it with a force called *gravity*. Meanwhile, the planets move around the Sun, and as Newton taught us, objects don't easily change direction once they are moving. This is called *inertia*. It is the balance of the planets' inertia and the Sun's gravitational pull that holds the planets in a continuous orbit around the Sun.

Now imagine hundreds of thousands of asteroids orbiting the Sun. Their orbits are not the same size and shape as Earth's orbit, which can cause our paths to cross. And because Earth is so much bigger than any asteroid, our gravity can pull them towards us.

Bonus! In the film, we see how gravity helped form the planets in our Solar System. How did gravity also stop some asteroids from forming into planets?



ASTEROIDS IN ORBIT

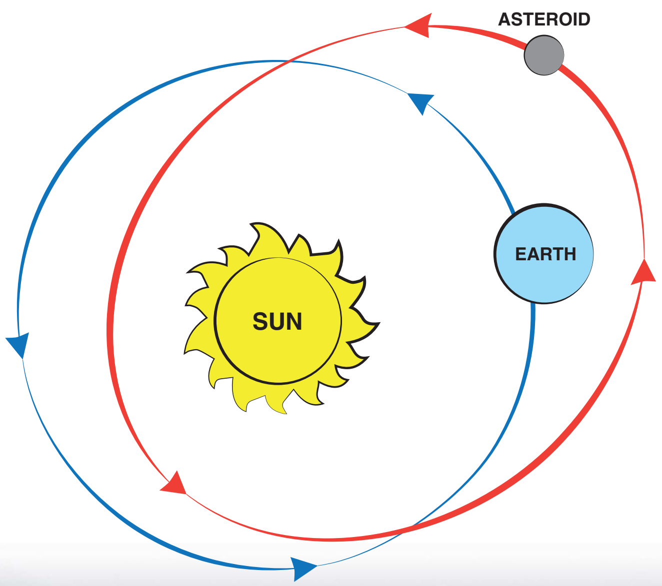
PART 2 CHANGING PATHS

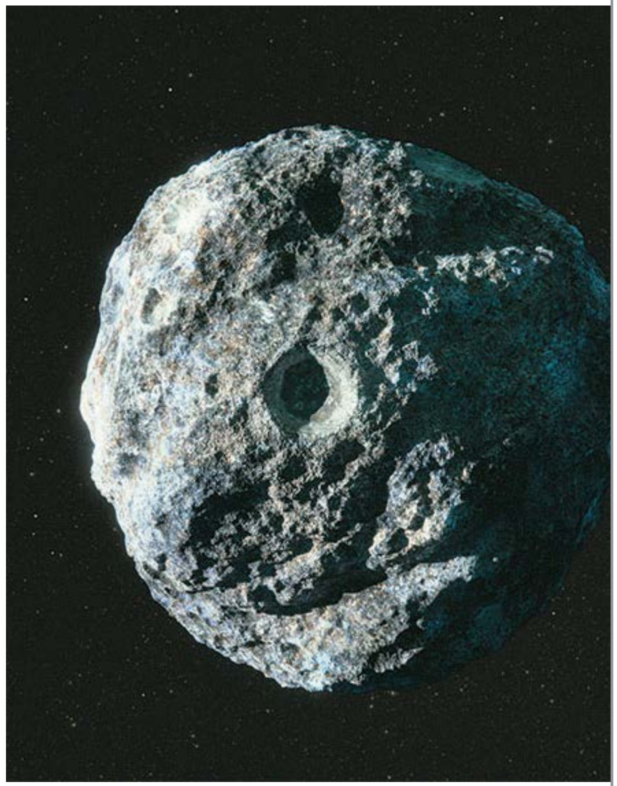
In ***Asteroid Hunters***, we meet scientists who track and study asteroids, and learn about ways they plan to prevent a collision with Earth. Most plans are to change the asteroid's path, either by explosives, a push, or even light from the Sun. Now it's your turn to come up with solutions. Put on your engineering hat and safety goggles, and head back out to the schoolyard.

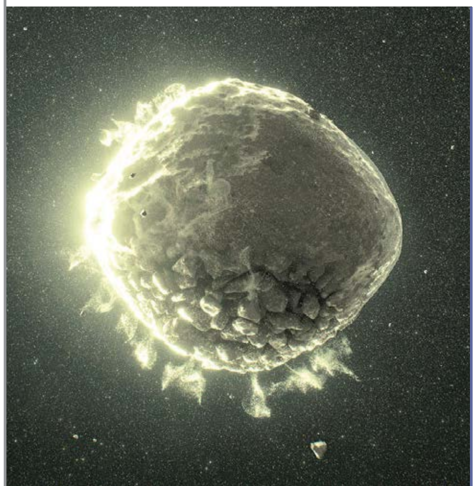
1. You will need several balls of various sizes. Roll your largest ball (Earth) on a smooth, flat area as your classmates try to hit it by rolling smaller balls (asteroids) towards it.
2. Now try to deflect the asteroids by rolling balls of various sizes towards them.
3. Try balls of different materials (spongy, hard, etc.) and write your notes about how well each one works.

Observations: Was it easy to *deflect* or move the asteroid off its path? What types of balls and rolling methods worked best? Did any of the balls cause a bigger collision, or hit Earth by accident?

Problem Solve: Now imagine that you have to create something to protect the Earth ball from an asteroid ball hitting it. What could you build that would deflect the asteroid ball, without damaging the Earth ball?







ABOUT ASTEROID HUNTERS

Asteroid Hunters is a spectacular new IMAX experience film that travels into orbit from the asteroid belt and back, showing us how remnants from the formation of the Solar System hold the keys to both our past and our future. Scientists believe that an asteroid impact is one of the greatest dangers facing Earth, but as we see in the film, they have embarked on incredible efforts to protect against such an event.

Target Audience:
These activities are designed for students in grades 6-8, as a supplement to environmental, Earth, and physics science curricula.

Objectives:
- *To introduce the space environment as part of the history of Earth*
- *To explore the opportunities and risks posed by asteroids orbiting near Earth*
- *To highlight some of the programs NASA and its partner agencies are conducting to study asteroids*
- *To teach standards-based lessons in physics and Earth science, and engage students in age-appropriate discourse and research*

Program Components:
- *This two-page teacher's guide*
- *Three reproducible activity sheets (two pages each)*
- *A standards alignment chart on page 19*
- *An online feedback form available at* **ymiclassroom.com/feedback-asteroid**

How to Use These Activities:
*Make copies of the activity sheets for students. Review the material and web resources before scheduling the activities. Each lesson should take approximately 20-40 minutes. While students do not have to see **Asteroid Hunters** to complete the activities, the activities are designed to enhance your students' viewing experience. Students can also complete the activities before viewing the film.*

National Standards:
These activities align with Next Generation Science Standards and Social Studies standards for grades 6-8. For standards correlation, see page 19.

WHAT ARE ASTEROIDS?
Instructions for Educator

Begin the program with a general discussion to assess what students already know about asteroids, meteors, and the Solar System. Ask if they have seen movies on these topics, and if those images were realistic or not. Then provide some time for students to complete the quiz. As you discuss the answers, guide students in an understanding of how our Solar System formed and how it has changed over 4.6 billion years, and what asteroids can tell us about that history.

Answers:

1) **A.** 4.6 billion years ago
2) **B.** Shooting stars (small objects are called shooting stars, large objects are called meteors)
3) **A.** Between Mars and Jupiter. Asteroids orbit the Sun just like planets. Scientists believe that Jupiter's gravity prevented the asteroids from combining into a planet.
4) **C.** Water. Asteroids contain a variety of metals and other chemical compounds that tell us about how they formed.
5) **B.** Arizona. Vesta is approximately 326 miles in diameter. Asteroids can range in size, from hundreds of miles across to smaller than gravel.
6) **B.** Binary pairs
7) **A.** 200
8) **C.** Less than the mass of the Moon
9) **B.** Near-Earth Objects (NEOs). As of January 2020, more than 20,000 NEOs have been discovered.
10) **B.** 2,000

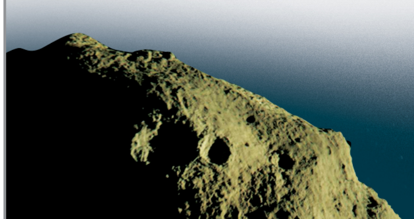
Extension:
Add an arts component to this lesson by having students make their own asteroids using clay and an assortment of pebbles, chalk fragments, beads, etc. An example can be found here: **jpl.nasa.gov/edu/teach/activity/modeling-an-asteroid**

MAKING A SPLASH
Instructions for Educator

Explain to students that when an asteroid enters Earth's atmosphere, it compresses the air in front of it, which generates heat and causes the asteroid to burn and create a flash of light called a *meteor* (also known as a shooting star). A meteor that survives the trip through the atmosphere and hits the ground is called a *meteorite*. At impact, a meteorite has a lot of kinetic energy, which is transferred into the ground when it crashes. The top layers of Earth are compressed, causing shockwaves, and are displaced in a spray of dirt and rocks called *ejecta*, which leaves a crater. The greater the energy, the larger the crater and the wider the ejecta pattern.

Materials Needed:

1. Pans or containers, at least several inches deep
2. A variety of powdery filler materials of different colors and densities, such as flour, cocoa powder, sand, potting soil, baking sprinkles, etc.



3. Small objects of various sizes and masses to use as meteors: rocks, marbles, magnets, beads, etc.
4. Safety equipment, including goggles

Instructions:

1. Divide the class into 3-4 groups and provide materials and activity sheets to each group.
2. Instruct students to layer the filler materials, one at a time, in their containers. The bottom layer should be the deepest, and the total should be 2"-3" deep.
3. Ask students to observe the differences in each object before beginning to drop them, and talk about how those differences might affect the impacts.
4. Provide time for the class to conduct the experiment and record the results.
5. Discuss the results of the experiment and the question answers.

Answers:

1) When you let go of the object, gravity caused it to fall; and the force of the filler materials and the container pushing up against the object caused it to stop.
2) The object's speed and kinetic energy would be much greater; therefore, the impact force would be much greater.
3) Earth doesn't change orbit because its mass is so much greater. Since F=ma, speed and kinetic energy is almost negligible when mass is so high. Diagrams should show that the force comes down from the asteroid at the same angle it was falling and fans out into the crater as a counterforce pushes up from Earth towards the asteroid.

Bonus Question:

During an impact event, kinetic and thermal energy are transferred via shockwaves into the earth. Prior to collision or explosion, the asteroid is moving very fast and has many forces acting upon it, so the amount of energy is enormous. This energy, in the form of soundwaves, causes windows to break—it's the same transfer of energy that causes the impact crater.

Extension:

In a real asteroid event, there would be additional forces to consider, such as air resistance from Earth's atmosphere, and velocity and mass would be much higher. Depending on your students' level of understanding, you can use this activity as a jumping off point for more complex lessons in energy and waves, such as a discussion of why asteroids burn up and even explode as they fall through our atmosphere.

WORKING TOGETHER

Instructions for Educator

Explain to students that scientists are working on developing solutions for mitigating asteroid disasters. The first step is in knowing as much about the dangers out there as possible. Discuss the projects described in Part 1, adding that there are many other explorations underway through private groups as well as NASA and its counterparts around the globe.

After students have completed Part 1, explain that technologies to deflect an asteroid are still being developed and tested. Many of them are still theoretical.

Answers:

Part 1: Answers will vary.

Part 2: Exact wording will vary; general definitions:

- *Nuclear Probe*: Uses a nuclear explosive to evaporate the outer layers of an asteroid to change its trajectory or increase its potential for missing Earth.
- *Gravity Tractor*: Uses the gravitational pull between objects in space to shift an asteroid's orbit by positioning a spacecraft near the asteroid, but not touching it.
- *Kinetic Impactor*: Shifts an asteroid's orbit by crashing a spacecraft into it to deflect it.
- *Solar Sail*: Uses the Sun's energy, through reflectors, to push the asteroid out of its trajectory.
- Additional ideas may include electrostatic pushing or using lasers to redirect asteroids.

Extension:

Some of the biggest and most impactful efforts towards asteroid detection and mitigation are international collaborations amongst multiple government agencies, university research departments, and/or private companies in different countries. Have students write or explain why they think it's important to take an international, collaborative approach to these efforts.

STEAM FOCUS

Add an arts component to this program:

- Before they view the film, ask students what they think it would sound and feel like to be orbiting in the asteroid belt or riding an NEO (Near-Earth Object) as it enters Earth's atmosphere and during an asteroid collision. Borrow instruments from the school's music department, or have students gather materials to make their own; then create a space soundtrack of this experience in the classroom. After students have seen the film, ask them how the soundtrack enhanced the dramatization.
- Have students illustrate the asteroid belt, Solar System, or an asteroid impact using charcoal pencils or collage.

RESOURCES

- Terrestrial Impact Craters **lpi.usra.edu/publications/slidesets/craters/crater_index.shtml**
- How NASA Studies and Tracks Asteroids Near and Far **jpl.nasa.gov/edu/news/2017/4/18/how-nasa-studies-and-tracks-asteroids-near-and-far/**
- Planetary Defense: Near-Earth Object Observations Program **nasa.gov/planetarydefense/neoo**
- Center for Near-Earth Object Studies: Planetary Defense **cneos.jpl.nasa.gov/pd/**

WHAT ARE ASTEROIDS?

In a spectacular new IMAX experience, ***Asteroid Hunters***, space will feel closer than you've ever imagined. You'll travel to the outer reaches of the Solar System and back to discover the origins of our planets and some dangers that may lurk ahead for our world.

There are hundreds of thousands of asteroids in our Solar System, and ***Asteroid Hunters*** will show you how scientists are studying them and why they matter. In the film, international scientists and engineers track the fictional asteroid Ficta A3D as it barrels towards Earth—watch and find out if it can be stopped.

HOW MUCH DO YOU ALREADY KNOW ABOUT ASTEROIDS?

Take this quiz to test your knowledge.

1. Asteroids are remnants left over from the early formation of our Solar System about:
   - ☐ A. 4.6 billion years ago
   - ☐ C. 4.6 million years ago
   - ☐ B. 460 million years ago
   - ☐ D. Don't know

2. When asteroids fall through Earth's atmosphere, air resistance causes them to burn up, creating a tail and flash of light. These are sometimes known as:
   - ☐ A. Comets
   - ☐ C. Meteorites
   - ☐ B. Shooting stars
   - ☐ D. Don't know

3. Most asteroids orbit the Sun within the main asteroid belt, which is located:
   - ☐ A. Between Mars and Jupiter
   - ☐ C. Between Earth and Venus
   - ☐ B. Between Jupiter and Saturn
   - ☐ D. Don't know

4. Asteroids are usually made of rock with bits of clay and metals like iron and nickel, but some asteroids contain:
   - ☐ A. Petroleum
   - ☐ C. Water
   - ☐ B. Diamonds
   - ☐ D. Don't know

5. The smallest asteroid that scientists have studied is 2015 TC25, a space rock only about 6 feet wide. The largest is Vesta, which is nearly as wide as:
   - ☐ A. Rhode Island
   - ☐ C. Texas
   - ☐ B. Arizona
   - ☐ D. Don't know

WHAT ARE ASTEROIDS?

6. Some asteroids have tiny moons that orbit around them, while others orbit together with a similarly sized partner; these are known as:

- ☐ A. Bola pairs
- ☐ B. Binary pairs
- ☐ C. Balanced pairs
- ☐ D. Don't know

7. Most asteroid impact craters on Earth have been worn away by erosion, but with new technology, scientists have now located about ______ craters on Earth.

- ☐ A. 200
- ☐ B. 500
- ☐ C. 1,000
- ☐ D. Don't know

8. Scientists believe that there are about a billion asteroids in the Solar System and that the total mass of all the asteroids combined is:

- ☐ A. More than the mass of the Sun
- ☐ B. Equal to the mass of Earth
- ☐ C. Less than the mass of the Moon
- ☐ D. Don't know

9. Asteroids that orbit within 18.6 million miles of Earth's orbit are classified as:

- ☐ A. Extraterrestrial Objects (ETOs)
- ☐ B. Near-Earth Objects (NEOs)
- ☐ C. Deep Space Objects (DSOs)
- ☐ D. Don't know

10. Asteroids that orbit within 4.65 million miles of Earth and are large enough to survive a fall through our atmosphere are classified as Potentially Hazardous Asteroids (PHAs). So far, scientists have identified about ______ PHAs.

- ☐ A. 20,000
- ☐ B. 2,000
- ☐ C. 200
- ☐ D. Don't know

FRONT ROW SEATS! Reading about asteroids on paper is no comparison to experiencing ***Asteroid Hunters*** in IMAX. If you get the chance to see the movie, write two new questions based on asteroid facts and technologies you learn and quiz a friend.

1) ____

____

2) ____

____

MAKING A SPLASH

In ***Asteroid Hunters***, we see that the Moon is covered in surface craters from asteroid impacts. Earth has craters, too, but because our planet's surface has changed so much over millions of years, they're much harder to see. Find out how craters form with a simple experiment.

1. Your teacher will provide you with a deep container and several filler materials like flour or cocoa powder. Layer these materials, one at time, into your pan to create a model of Earth's surface.
2. Gather a series of small objects such as pebbles, marbles, and magnets. These will be your asteroids.
3. Working with your group, take turns dropping the objects from different heights into the pan, and measure the craters that form. Since asteroids can come from many different directions, drop your objects from a variety of angles. Watch how the layers of "dirt" spray out from the center in different patterns called *ejecta*. Be sure to wear safety goggles for the experiment.

Hypothesis: Before you begin, how do you think the size and speed of the falling object (or asteroid) will affect the size of the crater and the ejecta pattern?

____

____

____

____

Data: Record your findings in the chart below and use the back of this page to make notes and draw pictures. Follow the example listed.

ASTEROID	DIRECTION OF IMPACT	CRATER DEPTH	CRATER WIDTH	EJECTA PATTERN
Small Pebble	Straight down			
Small Pebble	45° angle			

MAKING A SPLASH

Conclusion: Once you've conducted your experiment several times using a variety of objects, discuss the results with the class. Write a statement summarizing how the size of the object and the distance from which it fell affected the dimensions of the crater. Explain what the size of the crater and the ejecta pattern tell us about the amount of kinetic energy that was transferred.

Evaluate: On the back of this sheet or a separate paper, answer each of the questions below.

1. Newton's first law tells us that an object will continue moving at the same speed unless force is exerted on it. What force(s) caused the asteroids in your experiment to fall? What force(s) caused them to stop?
2. Newton's second law tells us that force is equal to the mass of an object times its acceleration (F=ma). How would the force of impact be different if the asteroid was shot from a machine instead of dropped?
3. Newton's third law tells us that whenever there is an interaction between two objects, equal force is exerted on both objects. If equal force is exerted onto the Earth during a collision, why doesn't Earth itself change its orbit? On the back of this page, draw a diagram depicting the forces on the asteroid and Earth at the point of impact.

Bonus Question: In the film's footage from a 2013 meteorite crash in Chelyabinsk, Russia, we see windows breaking. How does the transfer of energy that causes an impact crater also cause windows to break? Draw a diagram to illustrate this.

WORKING TOGETHER

In ***Asteroid Hunters***, we watch with anticipation as the fictional asteroid Ficta A3D appears on a crash course towards Earth. We stand with dozens of scientists and engineers, wondering as they try to deflect its path with a nuclear probe. Will they succeed?

Most asteroids that enter our atmosphere burn up before they ever come close to the ground, but scientists know that the real question is not IF an asteroid will hit Earth again but WHEN. That's why space-faring agencies around the globe are working to track, study, and measure asteroids that pose a threat to Earth's safety, and to devise and test systems that will protect us.

PART 1 TRACKING AND STUDYING

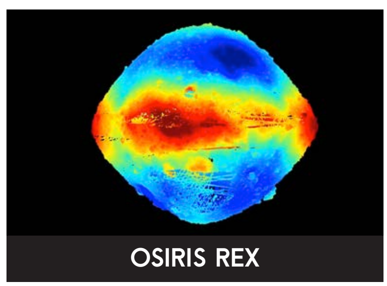
First, scientists need to know where the asteroids are and what they're made of. These profiles describe just a few of the programs NASA and partner agencies have launched to track asteroids and study their trajectories. Conduct research on Near-Earth Objects (NEOs) and planetary defense to learn more. Start with NASA's planetary defense website, **nasa.gov/planetarydefense/neoo**. On the back of this sheet, write three facts you find interesting and share them with the class.

NEOWISE

NEOWISE is part of a telescope that orbits Earth and uses infrared cameras to capture images of even very dark objects usually hidden by atmospheric haze. NEOWISE has scanned the skies 12 times, collecting information on the size and properties of asteroids, and offering a view into how NEOs orbit over time.

PAN-STARRS TELESCOPE

NASA can find bright asteroids from the ground using powerful telescopes, like Pan-STARRS1 in Hawaii, that capture and scan images taken every several minutes. An object that changes position in each image, relative to the stars around it, will be identified as an asteroid.



OSIRIS REX

This spacecraft has been tasked with gathering data about Bennu, an asteroid that scientists believe could pose a great threat to Earth in the next century. It will take samples of the rock for study and use laser rays to map the surface.

GOLDSTONE RADAR IMAGERY

In the film, Marina Brozović from NASA's Jet Propulsion Laboratory explains that her team bounces radar signals off space objects, and uses the transmissions to model images of them.

Image Sources: Pan STARRS - https://panstarrs.stsci.edu | NEOWISE - https://www.jpl.nasa.gov/missions/neowise/
OSIRIS REx - https://www.nasa.gov/image-feature/goddard/2019/osiris-rex-captures-laser-3d-view-of-bennu
Goldstone - https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA20043

WORKING TOGETHER

PART 2 DEFLECTING

The more we learn about asteroids, the better prepared we can be. But just what can we do to stop them? The Asteroid Impact and Deflection Assessment (AIDA) mission is a program of NASA and the European Space Agency that is testing how kinetic energy can be used to change an asteroid's trajectory using a probe, similar to what we see in ***Asteroid Hunters***. Below are some other suggested asteroid defense technologies. Research and describe each one, and explain what you think are the pros and cons of each method. Here is a link to get you started: **neoshield.eu/mitigation-measures-kinetic-impactor-gravity/**.

NUCLEAR PROBE:

Description: ______________________________

Pros: ______________________________

Cons: ______________________________

GRAVITY TRACTOR:

Description: ______________________________

Pros: ______________________________

Cons: ______________________________

KINETIC IMPACTOR:

Description: ______________________________

Pros: ______________________________

Cons: ______________________________

SOLAR SAIL:

Description: ______________________________

Pros: ______________________________

Cons: ______________________________

PART 3 CREATING A PLAN

Using what you've learned about existing ideas for studying and, if necessary, deflecting asteroids, come up with your own idea for protecting Earth from an asteroid collision. Keep in mind general science principles of gravity, energy, and motion, like Newton's laws. On the back of this sheet, write a brief description of your technology, and illustrate, collage, or construct a model of how you think it would work.

ABOUT ASTEROID HUNTERS

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- *An online feedback form available at* **ymiclassroom.com/feedback-asteroid**

How to Use These Activities:
Make copies of the two activity sheets for students. Review the material and web resources before scheduling the activities. The first lesson should take approximately one class period. The second activity can be extended into a longer unit. While students do not have to see ***Asteroid Hunters*** *to complete the activities, the activities are designed to enhance your students' viewing experience. Students can also complete the activities before viewing the film.*

National Standards:
These activities align with Next Generation Science Standards and Social Studies standards for grades 9-12. For standards correlation, see page 20.

TRACING THE PAST

Instructions for Educator

In this activity, students will learn how scientists study asteroids and why. Start the lesson by explaining that asteroids and other space objects can provide us with valuable information about the history of the Solar System and that scientists consider an asteroid hitting Earth to be one of the biggest dangers to our planet. Distribute the activity sheet and provide time for students to read the article and answer the questions in Part 1, then discuss their answers as a class. If students don't have access to the Internet in class, print out copies of the article: **nasa.gov/feature/jpl/cosmic-detective-work-why-we-care-about-space-rocks**.

For Part 2, explain that scientists also study existing impact craters to unlock important parts of Earth's history, such as the extinction of dinosaurs. Give students time to research impact craters and write up their findings. Then have them share their discoveries with the class.

Answers:

Part 1: Exact wording will vary.

1) Particles of dust, rock, ice, and metal avoided falling into the Sun or being flung out of the Solar System, and now orbit the Sun just like planets. Scientists believe that Jupiter's gravity prevented these particles from combining into a planet.
2) Study of asteroids and comets can help us understand how planets including Earth formed, locate hazards from incoming objects, and think about the future of exploration. It can tell us about the growth of planets from smaller objects, and if small planets may have provided Earth with ingredients for life.
3) It is thought that up to 80 percent of Earth's water may have come from small bodies like Bennu. Learning about the presence of water can help scientists better understand the kinds of objects that helped bring life to Earth and form theories about the formation of the Solar System.
4) Learning about the composition of asteroids can help us better understand the potential hazards of asteroids to Earth and what it would take to deflect them.
5) Asteroids may serve as future fueling stations for spacecraft and possible sites for mining.

Part 2: Answers will vary.

Extension:
Have students plot each of the impact sites they study on a globe or world map, and then discuss the similarities and differences between the locations. Impact sites are random, but are there similarities between the ways the land has eroded or the ecology has grown since the impact?

DEFENDING THE FUTURE

Instructions for Educator

This lesson gives students an opportunity to synthesize the information they researched in Activity 1, along with what they may have learned from watching the film. It will also help them develop group planning and organizational skills. (Students who are unable to see the movie can review some of the web resources listed below on asteroid deflection and mitigation.) Introduce the activity by talking about the efforts of NASA and other organizations to prevent asteroid collisions. Provide time for students to complete the short question section based on the film. Then divide them into groups.

Lead a discussion about what might happen if there were an asteroid impact in various places: a major city like New York City or Tokyo; a small, rural village in South America or West Africa; or the ocean, along the coastline or far out to sea. Ask students where they think an impact would be the easiest and hardest to manage. Ask each group to choose a location for further examination—make sure they choose locations where people live and work to assure a full scope for each project. Provide time in class over several days for groups to meet and discuss their projects. Encourage them to research similar disasters and how they were handled in the past. Once they have outlined their plan, extend the activity by having them put together a visual presentation to share with the class.

Answers:

Part 1: Exact wording will vary:

- *Observer Probe*: A spacecraft that travels to an asteroid to record its movements, including changes in its surface after a deflection attempt.
- *Nuclear Probe*: A spacecraft designed to explode the outer layers of an asteroid in an attempt to shift its trajectory and increase its potential for missing Earth. In the film, this is the method scientists choose to deflect the fictional asteroid Ficta A3D, but there are several other ways to cause an asteroid to miss Earth.
- *Computer Simulation*: Scientists use complex algorithms to estimate what would happen in an asteroid collision based on mathematical data about the asteroid and its trajectory.
- *Additional technologies include*: NEOWISE, Pan-STARRs, Goldstone radar imaging, and OSIRIS-REx.

Part 2: Projects will vary.

Extensions:

- Asteroid Day (June 30), sponsored by the Asteroid Foundation, is a program helmed by astronauts and scientists from around the world, seeking to bring attention to the risks posed by asteroids in the near future. Using what they've learned, have students create a poster or handout to raise awareness about asteroids and the organization.
- Direct students to research asteroid tracking efforts outside the scope of NASA and the European Space Agency (ESA), such as the Asteroid Decision Analysis and Mapping (ADAM) Project, and the Large Synoptic Survey Telescope (LSST) and summarize why they think asteroid detection and mitigation should involve private industry as well as government organizations.

STEAM FOCUS

Add an arts component to this program:

- Before they view the film, ask students what they think it would sound and feel like to be orbiting in the asteroid belt or riding an NEO (Near-Earth Object) as it enters Earth's atmosphere and during an asteroid collision. Have students create a relevant soundtrack for the experience as they imagine it. The soundtrack can be a musical score using real or homemade instruments, or series of sound effects. After students see the film, ask them how the movie's soundtrack enhanced their sensory experience.
- Have students create an original artwork depicting the asteroid belt, Solar System, or an asteroid impact using charcoal pencils, gouache, or collage.

RESOURCES

- Cosmic Detective Work: Why We Care About Space Rocks **nasa.gov/feature/jpl/cosmic-detective-work-why-we-care-about-space-rocks**
- Terrestrial Impact Craters **lpi.usra.edu/publications/slidesets/craters/index.shtml**
- OSIRIS-REx **nasa.gov/osiris-rex**
- Solar System Exploration: Dawn **solarsystem.nasa.gov/missions/dawn/overview/**
- How NASA Studies and Tracks Asteroids Near and Far **jpl.nasa.gov/edu/news/2017/4/18/how-nasa-studies-and-tracks-asteroids-near-and-far/**
- Planetary Defense: Near-Earth Object Observations Program **nasa.gov/planetarydefense/neoo**
- Asteroid Impact & Deflection Assessment (AIDA) Collaboration **www.esa.int/Safety_Security/Hera/Asteroid_Impact_Deflection_Assessment_AIDA_collaboration**
- OSIRIS-REx Captures Laser 3D View of Bennu **nasa.gov/image-feature/goddard/2019/osiris-rex-captures-laser-3d-view-of-bennu**
- Pan-STARRS1 Data Archive **panstarrs.stsci.edu/**
- Mission to Asteroids and Comets: NEOWISE **jpl.nasa.gov/missions/neowise/**
- B612 Asteroid Institute's Asteroid Decision Analysis and Mapping (ADAM) Project **b612foundation.org/asteroid-decision-analysis-mapping-adam-project-update/**
- Large Synoptic Survey Telescope **lsst.org**
- NASA/JPL NEO Deflection App **cneos.jpl.nasa.gov/nda**

TRACING THE PAST

In a spectacular new IMAX experience, ***Asteroid Hunters***, the origins of our Solar System will feel closer than you've ever imagined. You'll travel to the outer reaches of space and back to discover what scientists believe is the biggest threat to our planet—and what they're doing to try to stop it.

PART 1 SEARCHING THE SKIES

As you'll discover in ***Asteroid Hunters***, there are hundreds of thousands of rocky, airless objects orbiting the Sun, fragments remaining from the creation of our Solar System 4.6 billion years ago—asteroids. They range in size from grains of dirt to mountains, and can be made of any variety of rock, clay, minerals, and metals. Some even contain water and carbon molecules—the building blocks of life.

Asteroids that orbit within 18.6 million miles of Earth's orbit are called Near-Earth Objects (NEOs). Potentially Hazardous Asteroids (PHAs) are a sub-class of NEOs that pass within 4.65 million miles of Earth or closer, and are large enough to cause considerable damage if they fell through our atmosphere. Although asteroids just 50 meters in diameter can form a crater, PHAs are generally 500 meters or more in diameter. So far, scientists have identified more than 20,000 asteroids close enough to endanger Earth, and that number is growing. NASA estimates that there are almost 5,000 PHAs, but only about 2,000 have been found.

Teams of scientists around the world study asteroids to learn more about Earth's past—and our future. Read the following article from NASA's Jet Propulsion Laboratory to learn more, and use it to answer the questions below: **nasa.gov/feature/jpl/cosmic-detective-work-why-we-care-about-space-rocks**.

1. How did gravity help to form the asteroid belt?
2. What can asteroids tell us about the history of our Solar System?
3. What can scientists learn from the presence of water on some asteroids like Ceres and Bennu?
4. Why is it important to learn about the composition of asteroids, particularly the ones classified as Near-Earth Objects (NEOs)?
5. What opportunities do asteroids present for the future?

PART 2 EVIDENCE ON EARTH

The surfaces of the Moon and Mars are battered with craters from asteroid impacts occurring over millions of years. Scientists have discovered that Earth's surface is battered too—but these craters have been hidden or altered by erosion, plate tectonics, and other shifts in our planet's surface. The discovery of one such crater, in Chicxulub, Mexico, changed the understanding of the dinosaur's extinction.

By studying impact craters on Earth, scientists can learn about Earth's past, and, perhaps more importantly, about what to expect if we were to get hit by an asteroid again. For example, in the Tunguska event in 1908, only very tiny fragments of the asteroid were ever found—scientists know, therefore, that the energy and heat were likely caused by an explosion miles above the ground rather than the asteroid actually crashing into the ground.

Choose one historic crater or impact site to research. Describe how scientists discovered it was a crater and any challenges they faced identifying it. Then use the back of this sheet to write down two to three facts that the impact site can tell us about Earth's history or about what might happen in a future asteroid impact. Here is a link to get you started: **lpi.usra.edu/publications/slidesets/craters/index.shtml**.

DEFENDING THE FUTURE

Scientists believe that it's not a matter of IF an asteroid will hit Earth again; it's a matter of WHEN and WHERE.

As we see in ***Asteroid Hunters***, even a small meteor would crash with enough energy to permanently change our world—not only would people need to be evacuated for hundreds of miles from the impact zone, but in today's global economy, the impact would be felt around the world.

PART 1 CURRENT PROJECTS

Asteroid Hunters gives us a glimpse at some of the work scientists and space agencies are doing to deflect future asteroid impacts and/or reduce their damage. For example, we meet Marina Brozović, a scientist at NASA's Jet Propulsion Laboratory who uses radar beams to study asteroids from the Mojave Desert.

What other technologies do you see in the film? Start with the three examples below. Record some details you learned about each one, and then add two of your own.

- Observer Probe: ______
- Nuclear Probe: ______
- Computer Simulation: ______
- ______
- ______

PART 2 PLANNING COMMITTEE

Now, it's your turn. Get together with a group of classmates and imagine that you are a coalition of scientists, engineers, emergency managers, and political leaders. There is an asteroid headed for Earth that is expected to hit in 6 months. A computer simulation estimates that after burning through our atmosphere, the asteroid will be approximately 150 feet in diameter when it approaches the surface, about double the 2013 Chelyabinsk meteor seen in the film. Your teacher will work with you to select a location to study. Use this sheet to outline your planning.

Location

- *What are the unique hazards presented at this location?*
- *What advantages does this location have in terms of harm reduction?*
- *Besides safety of residents, what might be the ecological or economic effect of an impact in this location?*

Deflection

- *What method will you use to try to deflect or eliminate the asteroid? You can choose one discussed in the film or devise your own strategy.*
- *Why do you think this is the best option?*

Evacuation

- *If impact is inevitable, how will you keep people safe?*
- *Where will you send people, assuming you need to evacuate for hundreds of miles?*
- *How will you get food and water to displaced residents?*
- *How will you handle communications and electricity, if at all?*
- *What systems will you implement for keeping as much of the economy as possible intact?*

Present Your Plan!

Once you've outlined a plan with your group, put together a presentation or model of your strategy for deflection and harm reduction to share with the class.

GRADES 3–5 NEXT GENERATION SCIENCE STANDARDS*	**ACTIVITY:** Asteroids In Orbit
3-PS2-1 Motion and Stability: Forces and Interactions Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.	X
3-PS2-2 Motion and Stability: Forces and Interactions Make observations and/or measurements of an object's motion to provide evidence that a pattern can be used to predict future motion.	X
3-5-ETS1-2 Engineering Design: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.	X
4-PS3-3 Energy: Ask questions and predict outcomes about the changes in energy that occur when objects collide.	X
4-PS3-1 Energy: Use evidence to construct an explanation relating the speed of an object to the energy of that object.	X

GRADES 6–8 NEXT GENERATION SCIENCE STANDARDS*	**ACTIVITY:** What Are Asteroids?	**ACTIVITY:** Making A Splash	**ACTIVITY:** Working Together
MS-ESS3-2 Earth and Human Activity: Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.			X
MS-ESS1-4 Earth's Place in the Universe: Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history.	X		
MS-PS2-4 Motion and Stability: Forces and Interactions Construct and present arguments using evidence to support the claim that gravitational interactions are attractive and depend on the masses of interacting objects.			X
MS-PS2-1 Motion and Stability: Forces and Interactions Apply Newton's Third Law to design a solution to a problem involving the motion of two colliding objects.		X	
MS-PS3-1 Energy: Construct and interpret graphical displays of data to describe the relationships of kinetic energy to the mass of an object and to the speed of an object.		X	
MS-PS3-5 Energy: Construct, use, and present arguments to support the claim that when the kinetic energy of an object changes, energy is transferred to or from the object.		X	
NATIONAL CURRICULUM STANDARDS FOR SOCIAL STUDIES**			
Thematic Strand 9: Global Connections Social studies programs should include experiences that provide for the study of global connections and interdependence.			X

* NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

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GRADES 9–12

NEXT GENERATION SCIENCE STANDARDS*	ACTIVITY: Tracing The Past	ACTIVITY: Defending The Future
HS-ESS1-6 Earth's Place in the Universe: Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.	X	
HS-ESS2-2 Earth's Systems: Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.	X	
HS-ESS3-1 Earth and Human Activity: Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.	X	
HS-PS2-3 Motion and Stability: Forces and Interactions Apply scientific and engineering ideas to design, evaluate, and refine a device that minimizes the force on a macroscopic object during a collision.		X
HS-ETS1-1 Engineering Design: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.		X
HS-ETS1-3 Engineering Design: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.		X
NATIONAL CURRICULUM STANDARDS FOR SOCIAL STUDIES**		
Thematic Strand 3: People, Places, and Environments Social studies programs should include experiences that provide for the study of people, places, and environments.		X
Thematic Strand 9: Global Connections Social studies programs should include experiences that provide for the study of global connections and interdependence.		X

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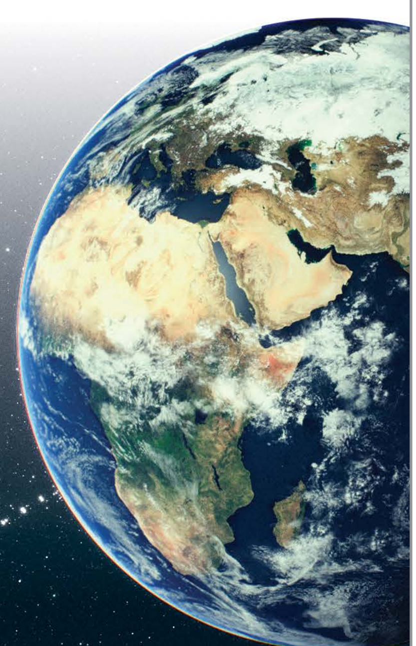

Activity Development: Young Minds Inspired

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ASTEROID HUNTERS

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