Saving Earth with Newton's Law of Universal Gravitation

Adapted from an activity © 2013 Texas Instruments
Help: http://www.cemetech.net/forum or stemspace@cemetech.net

Objectives

- Students will interpret graphs based on their interactions with a simulation that leads to a deeper understanding of the inverse square law.
- Students will be immersed in a hypothetical urgent issue and will be required to come up with possible solutions.
- Students will explore the different variables that make up Newton's law of universal gravitation.

Vocabulary

- Collision
- Asteroid
- Torino Scale
- Trajectory
- Gravitational Constant
- Density
- Inverse-Square Law

- Tsunami
- Impact
- Near-Earth Objects
- Velocity
- Gravitational Force
- Newton's Law of Universal Gravitation

About this Lesson

- This lesson introduces the concept of Newton's law of universal gravitation using a fictional rogue asteroid named 2014TX, which is on a collision course with Earth.
- Teaching time: one to two 45-minute class period(s)
- As a result, students will:
  - Interpret graphs to make predictions.
  - Use simulations to understand the inverse-square law as it relates to Newton's law of universal gravitation

Lesson Files

- Student Activity: Earth_Impact_Student.pdf
- Teacher Notes: Earth_Impact_Teacher.pdf *(this document)*
- ERTHIMPT.8xp and EITD.8xv: Activity program files. Must be sent to handheld's Archive.
- Doors CSE 8.1, which provides necessary extra program functionality. *(Not included: download at http://dcs.cemetech.net).*

Background

STEM - This activity portrays a scenario in which a team of scientists, engineers, mathematicians, programmers, and other experts have come together to determine solutions for how to deflect a rogue asteroid from colliding with Earth. The asteroid in question is, of course, fictional, but it is important for students to understand that Earth has had collisions in the past and will continue to have collisions with near Earth objects (NEOs) in the future. For dramatic effect, the asteroid portrayed in this activity is on the extreme side of both size and density.

SIMULATION - This particular activity starts by encouraging students (team members) to experiment with a simulation created by a fictitious teammate who is known to be a great computer programmer. The students should experiment with each of the variables in the simulation while monitoring the behavior of the asteroid. This will give them a visual sense of the scenario. Explain to them that there are problems with any simulation trying to represent reality, but simulations are intended to be used as tools for understanding, and are not exact replicas of nature. This provides an opportunity to generate a great discussion on the limitations of any model used to solve a problem.

NEWTON'S LAW - The activity progresses to focus on each component of Newton's law of universal gravitation and culminates with students performing some calculations embedded with inquiry-style questions. The aim is to have students understand that when distance is reduced by half, the gravitational force between Earth and the asteroid increases by 4 times. The square of the distance is inversely proportional to the gravitational force. Finally, students will reach a simulation in which the asteroid misses Earth, thus sparing our planet from destruction.

Send files to your TI-84 Plus C Silver Edition

Using TI-Connect 4.0 or higher, or a classmate's calculator, send the program ERTHIMPT (ERTHIMPT.8xp) and the AppVar EITD (EITD.8xv) to your TI-84 Plus C Silver Edition. Both files should go to your calculator's Archive.

- **Using TI-Connect:** Open TI DeviceExplorer and select your calculator. Drag ERTHIMPT.8xp into the item labeled "Flash/Archive" and wait for the transfer to complete. Drag EITD.8xv into "Flash/Archive" as well.
- **From another calculator:** Put the receiving calculator in Receive mode by pressing `2nd` `XTθn` `▶` `ENTER`. On the sending calculator, go to the `Link` menu with `2nd` `XTθn`, choose `2: All–…`, then find "`ERTHIMPT     PRGM`" and "`EITD      AVAR`" and press `ENTER` next to each one. Each one should be marked with a square, indicating that it will be sent. Press `▶` `ENTER` to send the files over.

You will also need Doors CSE 8.1 or higher, which can be found at http://dcs.cemetech.net. The process of sending Doors CSE to your calculator is the same as above, and is also detailed in the Doors CSE readme document.
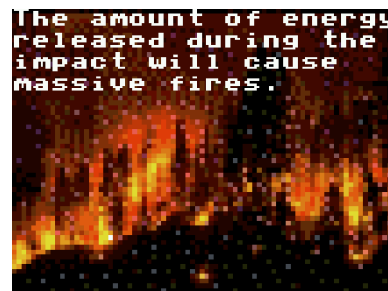

Run the ERTHIMPT program; move to pages 2-6

1. Run Doors CSE 8 from the Apps menu of your calculator, select ERTHIMPT, and run the program. You should see the Earth Impact! title screen. Throughout the Earth Impact activity, you can press the arrow keys (`◀` `▶`) to move between pages, or `ENT` to advance to the next page.

2. On a text page, press the `▼` and `▲` arrows to scroll down and up, or `ZOOM` or `ENTE` to scroll down.

3. Students will read the scenario in which a rogue asteroid is on a collision course with Earth. They will examine the artist-rendered images on each page to get an idea of what kind of devastation would happen if the asteroid hits Earth.

4. After students review the scenario and images, ask them: *Have you heard of any asteroids coming toward Earth?*

   Sample answers: Small objects hit Earth's atmosphere all the time. Shooting stars are meteoroids that have entered Earth's atmosphere and generate light from the heat of friction between the meteor and the atmosphere. Larger objects, such as asteroids, hit with less frequency. Most recently, the Chelyabinsk meteor buzzed Earth over

Russia on February 15, 2013. It was about 15 miles high when it exploded into smaller fragments. In some places, parts of buildings collapsed, windows were blown out and there were a large number of injuries from flying debris.

Move to pages 7-10

5. Page 7 explains a tool that astronomers use called the Torino Scale. They use the scale to categorize the impact hazard and amount of damage for a given NEO.

6. On page 10, students will use sliders to experiment with the starting angle (measured in degrees), the initial velocity (measured in km/sec), and the asteroid mass (measured in 100 million kg). For mass, the slider value is multiplied by 10^8. Students should explore the variables and observe what happens with each change. The final settings they use for their simulations will be used to generate three graphs later in the program.

To set the angle, velocity, and mass of the asteroid, press ZOOM, under the SET option. Use the arrow keys to move the sliders, then press ENTER to save your changes. To run the simulation, press TRACE, under the RUN option. When you're ready to move to the next page, press WINDOW or ▶.

Ultimately, the goal is to enable students to see that by changing the trajectory (angle) of the asteroid they will save the Earth. They should also notice that changing the mass doesn't significantly affect the outcome.

After students explore the simulation, ask:
After experimenting with the simulation, what ideas do you have for saving Earth?

Sample answers: Changing the angle of the asteroid will change its course. Changing the speed of the asteroid could also change its course. Changing the mass didn't seem to have much of an effect, because the mass of Earth is so much greater than the mass of the asteroid.

Move to pages 11-18. Answers to the questions are provided.

Q1. Adjust the variables to have the asteroid collide with Earth and then run the simulation again. Now explore the graphs on the next pages. What do you notice about the velocity of 2014TX compared to its distance from Earth? Circle one of the following:

Answer: (C) Velocity increases as distance decreases.

Q2. Look at the data on the velocity vs. time graph on the next page, which is based on the last parameters you set in the simulation. What point on the graph represents the point at which the asteroid is farthest from Earth? Which point represents the point at which the asteroid is closest to Earth?

Farthest = Velocity will typically be lowest the farther away the asteroid is from Earth.

Closest = Velocity will be highest when the asteroid is closest to Earth. On the graph these points are represented by the least amount of time for lowest velocity and most amount of time for highest velocity (just before impact).

Note: Some students may have an inflection point at the top of their velocity graphs. This indicates that the asteroid was "slingshotted" around and away from Earth.
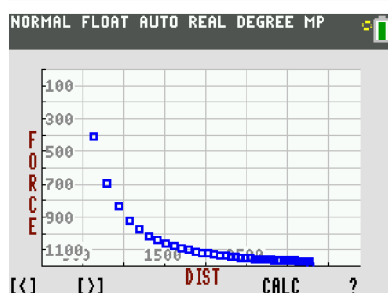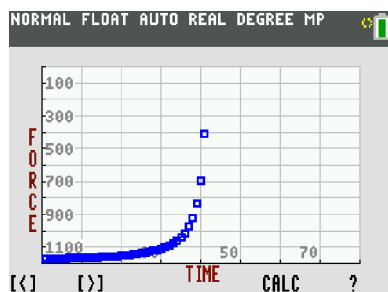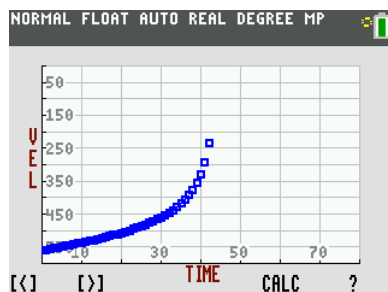
Q3. From the graph on page 13 (from Q2), how can we tell the asteroid is getting faster or slower (your answer from Q1) as it approaches Earth?

Answer: The increases in a nonlinear way. The velocity increases over time because the gravitational force produced by Earth is stronger as the asteroid gets closer, causing the asteroid to accelerate.

Q4. On the following two graphs, "FORCE" on the Y-axis represents the gravitational force between 2014TX and Earth. What can you say about the gravitational force as the asteroid gets closer to Earth?

Answer: The graph is increasing in a nonlinear way. The force increases as the asteroid approaches Earth. This is reflected over time and over distance in each of the two graphs.

Note: Although the students are not told this because of a future question, the TIME axes are measured in weeks.

Q5. Based on the data in the FORCE graphs, how are distance and gravitational force related?

Answer: B. Inversely. As the square of the distance decreases, gravitational force increases.

Move to the beginning of Section 2 on pages 19-22. Answers are provided here.

6. At this point, students will explore some physical characteristics of the asteroid, such as its volume and density. They will also calculate the mass. Students will give answers to the following questions.

> **Background**
> The team has deter-mined that the asteroid is composed of iron, which has a density of 8 g/cm^3 (8,000 kg/m^3). Satellite imagery has revealed that the asteroid is huge, with a volume of roughly 6 km^3.
>
> [<] [>]   CALC ?

Q6. If 2014TX has a density of 8 g/cm^3 (8,000 kg/m^3) and a volume of 6 km^3 or 6×10^9 m^3, calculate the mass of the asteroid. If you need a calculator, you can press TRACE to access one inside the Earth Impact! activity. If you exit Earth Impact! using CLEAR, it will resume where you left off when you run it again.

Answer: Students should use: density = mass/volume and solve for mass.

Mass = Density × volume

Mass = (8,000 kg/m^3) x (6×10^9 m^3) = 4.8×10^{13} kg

Q7. The asteroid is traveling at an average velocity of 25 km/sec. Based on a distance of 3.5 billion km from Earth, when will the asteroid hit Earth? Express your answer in days, and remember that there are 10^3 meters per kilometer.

Answer: Students will need to use: velocity = distance/time and solve for time.
time = distance/speed: (3,500 million km) / (25 Km/sec) = 1.4×10^8 seconds.
In days, this would be: (1.4×10^8 sec) × (1 hour/3,600 sec) × (1 day/24 hours).
= 1,620.37 days (4.44 years)

Q8. Based on your answer to the previous question, it may seem odd to worry about something that is years away. In your opinion, why is the team so worried about this situation?

Answer: Answers will vary. The point of this question is to have students realize that even though an event is several years away, to solve a monumental problem like this, it takes time, coordination, and urgency. In fact, NASA, today, would not be able to deal with such a threat if we weren't able to detect it years away from impact. It would take a few years to figure out what to do about it, which is why there is such urgency to solve the problem. We also want to deflect or destroy the asteroid as far away from Earth as possible, because the closer it gets to Earth, the faster it will be moving, which would make it tougher to deflect.

Move to pages 23-30. Answers are provided.

7. Pages 23 and 24 introduce Newton's law of universal gravitation as a tool to determine the gravitational force between Earth and the asteroid. Up to this point, students have experimented with different aspects of the equation in the simulation and calculations. Now, students will put that experience to work by using the actual equation. Ideally, they will see that the closer the asteroid is to Earth, the harder it will be to deflect.

   Important Note: The TI-Nspire version of this Activity incorrectly uses 3.5 billion km = 3.5 x 10^{13} meters rather than the correct 3.5 x 10^{12} meters. This TI-84+CSE activity fixes this, but therefore also has different answers than the TI-Nspire version.

```
Newton's Law of Uni-
versal Gravitation
F = G*(m_E*m_A)/r^2
F=Gravitation force
G=Gravitational
  constant=
6.67*10^-11 N*m^2/kg
m_E=Mass of Earth=
  5.972*10^24 kg
m_A=Mass of asteroid
  use your value
r=distance between
[<] [>] vvv CALC   ?
centers of Earth and
asteroid=3.5*10^12 m
```

Q9. Use the calculator to determine the force between the asteroid and Earth, and write the force you calculate here.

   Answer:
   Force_g = (6.67 × 10^{-11} N x m^2 / kg^2) x (5.972 × 10^{24} kg x 4.8 x 10^{13} kg) / (3.5 x 10^{12} m)^2 = 1560 Newtons

Q10. Now, determine the force between the asteroid and Earth if you cut the distance between them in half. Write your answer here.

   Answer:
   Force_g = (6.67 × 10^{-11} N x m^2 / kg^2) x (5.972 × 10^{24} kg x 4.8 x 10^{13} kg) / (1.75 x 10^{12} m)^2 = 6243 Newtons

Q11. Divide the last force you calculated, when the distance was cut in half, by the first force you calculated. In other words, divide the answer to Q10 by the answer to Q9. Round to the nearest whole number. Why is this number significant?

   Answer: ratio = 6243/1560 = 4.002   4

   The number is significant because it shows that when the asteroid is half the distance from Earth the gravitational force between them is four times as much! This means the energy upon impact will also increase proportionally.

Q12. The forces you calculated in the previous problem were very small due to the great distances. See what happens when r = 3.5 x 10^6 m and re-calculate the force. This is equivalent to the asteroid being only 3500 km from Earth!

   Answer:
   Force_g = (6.67 × 10^{-11} N x m^2 / kg^2) x (5.972 × 10^{24} kg x 4.8 x 10^{13} kg) / (3.5 x 10^6 m)^2 = 1.56 x 10^{15} Newtons

Q13.   NASA's Jet Propulsion Laboratory (JPL) constantly monitors asteroids and other NEOs and their trajectories. They are working on a project that will enable us to learn how to deflect these objects if they threaten to strike Earth. What are some possible methods you think JPL should consider when thinking about deflecting a real asteroid from hitting Earth?
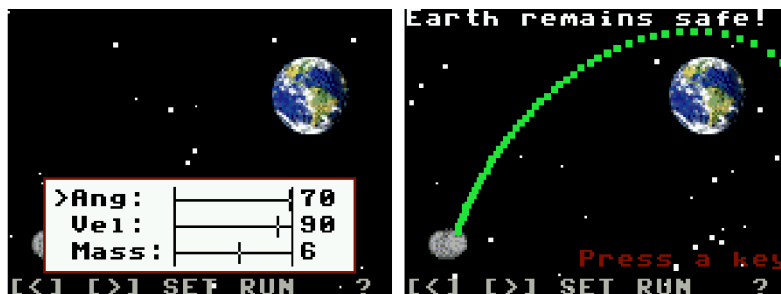
Answer: Answers will vary. Some answers may be to use missiles, send a crew of astronauts to land on the asteroid and plant explosives, or use another asteroid to create a collision.

Q14.   When the distance between Earth and the asteroid is cut in half, its gravitational force increases by the amount you calculated in Q11 (based on the inverse-square law). Based on this, what would you say about the importance of when to divert the asteroid?

Answer: Knowing that as the asteroid gets closer the force increases at a higher rate than the distance decreases, students should realize the speed of the asteroid will increase at a rate that is proportional to the increase in force. As such, deflecting the asteroid sooner rather than later would make the most sense, because changing its trajectory will get harder and harder the faster the speed of the asteroid.

Move to the final three pages, pages 31-33.

8.   Thanks to the work done by the team, the asteroid was diverted. Page 32 lets you test the results when the asteroid is diverted by a few extra degrees, narrowly missing Earth.

Wrap-Up

Students will have various results depending upon the angle and/or speed they have selected. Have students compare their graphs and discuss why the results are different.

Assessment

Students will answer questions throughout the lesson to ensure they understand the concept of Newton's law of universal gravitation, density, and distance vs. time.

Image Credits: NASA.gov. See readme.txt for full links.