Extreme Navigation

EDUCATOR GUIDE

Created for the EPOXI, Deep Impact and Stardust-NExT Missions
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Adapted by Stardust-NExT Education and Public Outreach

Activity Description
"Extreme Navigation" is designed for students in grades 5–8. In this activity, students take on the roles of a navigation team, spacecraft, comet, Earth, and Sun to simulate how mission planners design a spacecraft/comet rendezvous. This activity requires at least four active participants.

Parallels in Engineering
Mission designers use sophisticated mathematics and communication to plan and execute how a spacecraft travels along a trajectory in order to meet up with an object in space. Emphasize with your class the importance of math in planning an encounter with a comet and explain the value of doing well in mathematics. All students, particularly those interested in a career in engineering, should learn and experience applied mathematics as frequently as possible throughout their time in school.

National Science Education Standards addressed
Grades 5–8
Unifying Concepts and Processes
- Evidence, Models, and Explanation
  - Models are tentative schemes or structures that correspond to real objects, events, or classes of events, and that have explanatory power. Models help scientists and engineers understand how things work.

Science as Inquiry
- Abilities necessary to do scientific inquiry
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Use mathematics in all aspects of scientific inquiry.

Earth and Space Science
- Earth in the Solar System
  - Most objects in the solar system are in regular and predictable motion.

Physical Science
- Motion and Forces
  - The motion of an object can be described by its position, direction of motion, and speed.
  - That motion can be measured and represented on a graph.

Science and Technology
- Abilities of Technological Design
  - Design a solution or product.
  - Implement a proposed design.
  - Evaluate completed technological designs or products.

***National Council of Teachers of Mathematics Expectations* addressed:**

Grades 6–8

- Use symbolic algebra to represent situations and to solve problems, especially those that involve linear relationship.
- Model and solve contextualized problems using various representations, such as graphs, tables, and equations.
- Solve simple problems involving rates and derived measurements for such attributes as velocity and density.

Objectives

Students will:

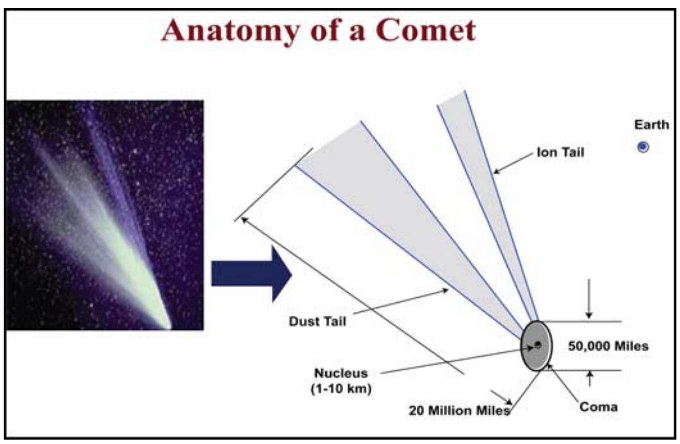
- plan a simulated mission for a spacecraft to rendezvous with a comet
  - simulate the Sun, Earth, spacecraft, and comet.
  - experience at a basic level the complex components of mission planning.
- develop an understanding of how comets, Earth, the Sun, and a spacecraft relate to each other in space.

Materials

- Open space, preferably outside.
- A minimum of 60 meters of thin clothesline rope or carpenter's string (in fluorescent colors and on a roller) to make your comet's orbit and spacecraft's path.
  - If using thin rope, cut the string in half. Roll each length separately onto an empty paper towel tube so they don't become entangled.
- Two marker pens to mark half meter lengths on both strings.
- Pieces of duct tape, stickers, or labels to mark the meeting point on the spacecraft path string with each calculation and to label the launch "trial" number at the Earth end.
- Scissors to cut the string.
- Clipboards and pencils/pens for each student.
- Student Role Sheets (one set per group) http://stardustnext.jpl.nasa.gov/education/xtreme_nav/RoleCards.pdf.
- Extreme Navigation PowerPoint http://stardustnext.jpl.nasa.gov/education/pdfs/ExtremeNav.ppt.

Advance Preparation

- Prepare two strings 30 meters in length. Place duct tape or other marks at every half meter interval on the string.
- Select an open area with ample room for students to move around.



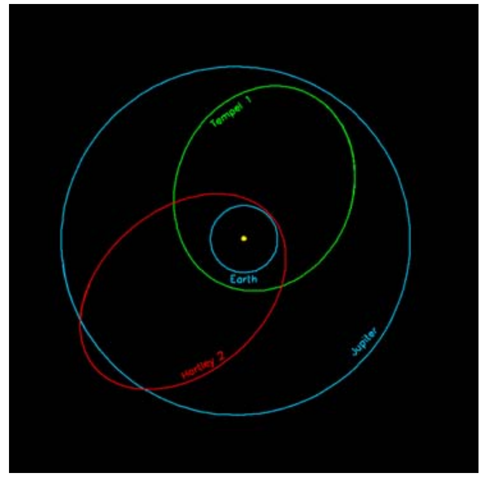
Procedure

INTRODUCTION

1. As a class, discuss what students think they know about comets. Use the diagram at right to explain the basic anatomy of a comet.
2. Use the PowerPoint slides to provide some mission context for both the Stardust-NExT and EPOXI missions.
3. Show the slide that depicts the orbits (the path that the bodies follow as they circle around the Sun) of Earth, Jupiter, Tempel 1, and Hartley 2 (shown at right). Ask students to explain the

similarities and differences in these orbits. (Students might indicate that, in both cases, the bodies orbit the Sun. Most students will notice that the comets' orbits are more "oval" in shape).

   a. Explain that spacecraft such as EPOXI and SD-NExT orbit the Sun (the misconception is that they orbit Earth, like a satellite), and have orbits that follow paths very similar to Earth's.



Comet orbits are ellipses (Hartley 2 and Tempel 1). Planet orbits are more circular (Earth and Jupiter).

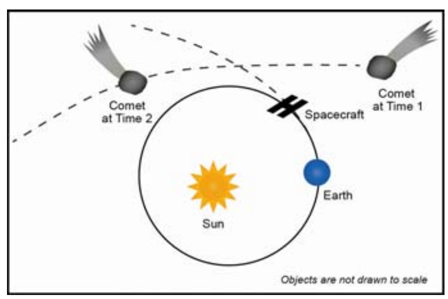
4. Read the following statement to your students. This will serve as their "briefing."

   - *NASA has funded your team to encounter a comet to see what it is made of and how it has changed since last visited. EPOXI will encounter comet Hartley 2 in November 2010 and Stardust-NExT will meet up with Tempel 1 in February 2011. One question you need to ask yourself is "What is the best way to get to a comet?" The mission teams of both the EPOXI and Stardust-NExT spacecrafts had to answer that very question. We will play a game so you can try to see how you would navigate a spacecraft to arrive at a comet.*

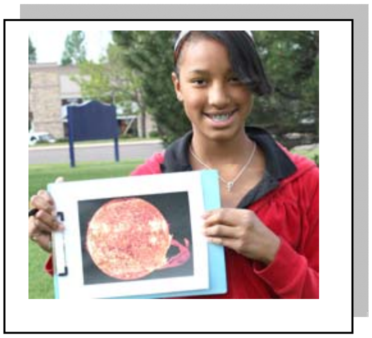
5. The mission engineers have determined that the spacecraft trajectory should overlap so it can pass by the comet in order to achieve the closest approach.
   a. When you launch your spacecraft, you must launch it in a counter clockwise direction (This is the way Earth rotates (spins) as seen from the North Pole and we use Earth's rotation to assist spacecraft into orbit.)
      i. Why does that make sense? (Uses the momentum of the Earth in rotation to give spacecraft extra boost, lower fuel requirements—model this with a spinning Earth-student and a spacecraft-student taking off from the Earth-student.)

SET-UP

6. Explain to students that they will take on different roles and that each group will be able to complete the simulation at least once. Distribute a different role sheet to each student in the group (if you choose to have groups larger than four students per group, you can have multiple mission planners). Have students read over the directions on their role sheets. While the first group participates in the simulation, other students should watch and learn from what happens to make improvements when it is their turn.
   a. Set the position of the Sun and Earth in your solar system.
   b. Set the position of the comet orbit string on the ground in an arc so that it orbits the Sun.
      i. The string is long enough to represent only a portion of the orbit.
   c. The navigation team will use the second length of string to represent the path (trajectory) your spacecraft will need to take in order to get to the comet, and then cross in front of it.
      i. Lay out a piece of string to represent the spacecraft path in an arc between Earth and a place they calculate will cross over the comet path so that the comet and spacecraft meet at the same time.

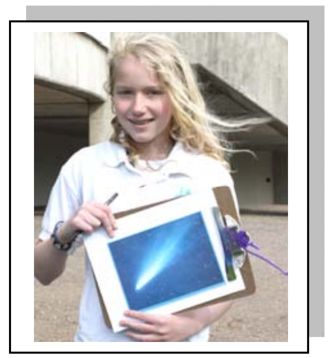


7. Each string will represent the same length of time, from launch to comet encounter. Once ready, the spacecraft, mission planners should all be near the Earth ready for "launch."



From left: Sun, Earth, and Navigation Team

Navigation Team members plan the spacecraft's trajectory so that it intersects the orbit of the comet



The student representing the comet should start on one end of the orbit and walk counter-clockwise around the Sun

LAUNCH

8. Explain that after the countdown, each second will represent two weeks of time.

9. **Comet:** Place a student at the furthest end of the comet orbit path to be the traveling comet.
    a. The comet/student is allowed to take one step for **one** second.

10. **Spacecraft:** Place one student next to the Earth who will travel the spacecraft path.
    a. The spacecraft/student begins at Earth and is allowed to take one step every **two** seconds,
        i. Results in the spacecraft moving half as far/fast as the comet.

11. Each student will begin from these points and take half meter steps according to the markings on the string with the toe of their shoe hitting the mark.

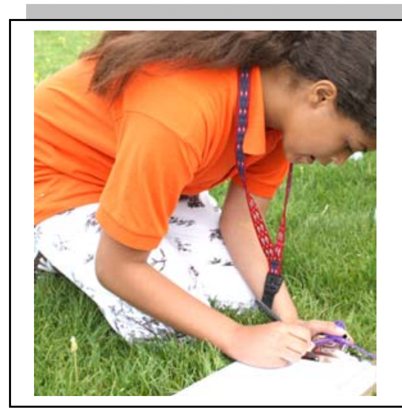
12. **Earth and Sun:** The Earth moves at the pace of the spacecraft in a counter-clockwise trajectory.
    a. If Earth/student is eager and has self-control, it may rotate slowly as it orbits to further model Earth's motion.
    b. The Sun/students takes notes and shines, observing the scene from its position at the center of the Solar System.

13. **Navigation Team:** Choose a timekeeper
    a. Give a 5 second launch countdown to give the comet and spacecraft students their timing. Have a student count in a loud voice. At the one second mark, the students representing the Earth, spacecraft, and comet should take their first step.
    b. They should move around the Sun in a counter-clockwise direction until time is called.

14. Both the spacecraft and comet keep moving on the beats until they get to the place where the strings cross (or intersect). Did the spacecraft and comet meet together at the same time? Did the spacecraft get in front of the comet?

Spacecraft encounters a comet!

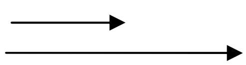
Spacecraft takes off from Earth



Student responds to questions on role sheet

- If they did not, have the class decide how to change the time of launch to make up for the difference and try it again. Then try your other two locations for the Earth at launch. Mark each trial with a label at the intersecting point and mark each location for Earth with the corresponding number. Have students answer the questions on their role sheets.
- Once the first group has completed the simulation, allow the next group to take their turn. Allow all groups a chance to simulate the extreme navigation before engaging the students in debriefing questions that follow.
- After your have conducted all of the simulations, return to the classroom. Provide students with the following symbols on the board. Ask them to use the symbols to illustrate and label the motion of the bodies as occurred in the simulations. Explain that the arrows represent the motion and relative speed of the comet and the spacecraft.

S = Sun
E = Earth



Informal Assessment Debrief Questions

1. Describe the comet's orbit. (Students should describe it as oval or, more correctly, an ellipse.)
    - What is the trajectory of the spacecraft? (The planned path that the spacecraft travels toward its destination.)
2. What made this simulation challenging?
    - Many students will state that figuring out where the comet will be when the spacecraft arrives was challenging. Others might say that because the comet and spacecraft were moving at different speeds.
3. What could have made this simulation more challenging?
    - Accept student responses. State that a comet speeds up relative to the Sun as it reaches the place in its orbit where it is closest to the Sun [perihelion].
4. How did you make improvements to your flight plan after your first trial (or by the benefit of watching the trials of the other groups)?
5. How was math important in planning a trajectory?

6. What did you learn about trying to encounter a comet in space? Why can't you aim for where the object is at the time of launch? (The comet will have moved.) Where did you have to aim? (Where the comet will be when the spacecraft arrives.)
7. If you were near the simulated Earth at the beginning of the activity, how did you feel after the spacecraft launched?
    - Many students on the Navigation Team may have felt out of control. You may also want to state that sometimes the navigation team can vary the approach of the spacecraft by conducting "trajectory correction maneuvers."
8. What did you notice about the motion of the bodies in the solar system?
    - Students should state that the bodies all moved all the time. Students should state that the motion was regular and predictable. You may want to point out that the Sun rotates (spins) and that the entire system revolves (orbits/travels) around the center of the Milky Way galaxy. Explain that to simulate this, the entire simulation would have to be conducted while on a large platform that moved around the school which would represent the galaxy.

Challenge: Moving Our Spacecraft/Comet Flyby Model Closer to the Real Thing

1. Calculate the length of comet string needed to intersect based on the different walking speed of the comet and spacecraft.
    a. You will need to measure the length of the comet string and make a mathematical plan to calculate the length of the spacecraft string needed.
    b. Since the comet travels twice the speed of the spacecraft in this formula, students will need to calculate not only the length but also the curve to make the encounter. Have the students place a label on their meeting place. In this exercise, label the intersection point before laying it out on the floor.
    c. The spacecraft string must arc toward the comet so the spacecraft can intersect with the end of the comet string. Have the students try to make the comet and spacecraft meet with the length they have labeled. Run the exercise with the timer.
2. When the correct length of the spacecraft path has been found and a successful encounter point is established, move the placement of the Earth around the Sun and "launch" the spacecraft again. Use the same timing for the steps.
    a. Moving the Earth around the Sun is a good exercise for understanding why there is an ideal time to launch and why other times of the year would not be as efficient. Have students discuss what new issues are raised as they have to re-calculate their trajectory.

Mathematics Extensions

- If the student comet travels 20 steps along its orbit (string), how many steps would you plan for the student spacecraft to travel to rendezvous with the student comet?
  Answer: 10 steps

- Based on your experience in this activity, develop an equation that represents the speed of the student spacecraft compared with the speed of the student comet.
  Answer: S = ½ C or 2 x S = C
  C = Speed of Comet
  S = Speed of Spacecraft

- If the student comet travels 60 meters per minute (fast kid), along its orbit (string), how much time is required for the student spacecraft to rendezvous with the student comet?
  Answer: 120 meters per minute

- Assuming that the student comet and the student spacecraft are moving at constant speeds and that the comet is 20 steps away from the Earth at time of launch, determine a formula that could be used to navigate successfully to arrive at the student comet every time.
  Answer: 2*Earth to comet distance = Point of rendezvous with Comet
  2* 20 Earth to Comet steps = 40 Comet steps in its orbit

Comet Rendezvous Missions

http://deepimpact.umd.edu/
Deep Impact's primary scientific theme is to understand the differences between the interior of a cometary nucleus and its surface.

http://epoxi.umd.edu/index.shtml
The primary task (DIXI or Deep Impact eXtended Investigation) is to fly past comet Hartley 2 in 2010. Along the way (Jan-Aug 2008) the spacecraft observed planets around other stars (EPOCh).

http://rosetta.jpl.nasa.gov/
The Rosetta spacecraft is on its way to *catch* and *land a robot* on a comet! Rosetta will reach comet "67P/Churyumov-Gerasimenko" ("C-G") in 2014. The European Space Agency (ESA) is spearheading this international mission, with NASA providing key scientific instruments for studying comet C-G and other celestial bodies.

http://sci.esa.int/science-e/www/area/index.cfm?fareaid=15
European Space Agency's (ESA) first deep space mission, Giotto was designed to help solve the mysteries surrounding Comet Halley by passing as close as possible to the comet's nucleus, which it achieved on 13 March 1986.

http://solarsystem.nasa.gov/missions/profile.cfm?MCode=ISEEICE
ISEE-3/ICE (International Cometary Explorer)
ICE studied two comets - comet Giacobini-Zinner and comet Halley – during its extended mission

http://stardust1.jpl.nasa.gov/home/index.html
The primary goal of the Stardust mission was to collect samples of a comet and return them to Earth for laboratory analysis.

http://stardustnext.jpl.nasa.gov/
Stardust-NExT will flyby comet Tempel 1 on February 14, 2011, to complete the exploration initiated by Deep Impact

Additional Resource

http://www2.jpl.nasa.gov/basics/index.php
The Basics of Space flight is a tutorial designed primarily to help operations people identify the range of concepts associated with deep space missions, and grasp the relationships among them. It also enjoys popularity with college and high-school students and faculty, and people everywhere who are interested in interplanetary space flight.