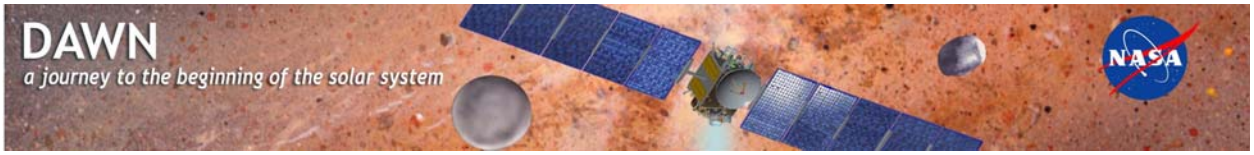


History and Discovery of Asteroids

Modeling Asteroids

TEACHER GUIDE—DEVELOPMENT

BACKGROUND

This section of the *History and Discovery of Asteroids* contains hands-on activities that can be used to help the students understand what astronomers in the historical flashbacks of the Exploration section were experiencing as they studied asteroids from Earth. These activities include:

“Patterns in the Sky”
“In Search of…”
“How Bright Are You?”
“Seeing Circles—Studying Albedo”
“Where Are You?”
“Modeling in 3-D”

Patterns in the Sky

The readings in the Exploration section of this module focused on the challenges associated with asteroid discovery, starting in the 16th century. Before the asteroids were discovered, however, mathematicians observed a “pattern in the sky” based on planetary distances from the sun. In one activity option of the same name, students use algebra to identify a gap in the solar system where a missing planet should be found. In doing so, students “discover” the Titius-Bode law. This law states, *“The mean distances of planets from the sun are approximately subject to an exponential rule.”* In the “active” modeling option of this activity, students will model the spacing between the planets so that the distance from the Sun to Saturn is equal to 100 steps.

In Search of...

The Titius-Bode law led to the discovery of a “missing planet” between the orbits of Mars and Jupiter. In this activity, “In Search of…,” students become members of the Celestial Police as they hunt for the missing planet. Students view quadrants of the sky in the form of star maps that simulate several nights of viewing. By using a blink test, students in each group will have an opportunity to “search for” the missing planet.

How Bright Are You?

The first generation of asteroid searchers found four asteroids in the seven years between 1801 and 1807. One of the reasons they discovered so many, of course, was the fact that the “First Era” asteroid searchers found the four largest and brightest of the “minor planets.” The remaining asteroids may have been too small and too dim to be seen, even with the best telescopes available in the early 1800s.

Students may also research the size of the first 10 asteroids discovered and graph their sizes vs. the date of discovery to determine which factor—brightness or size—played the greater role in their discovery.

The brightness of an asteroid, a critical factor for discovery, depends upon its distance from the Earth, its position in its orbit, what part of its surface is facing the sun, and the albedo of this reflecting surface.

In the “How Bright Are You?” graphing activity, students will use the information in the flashback, “What Can You See With a Telescope?,” to plot the date of discovery versus the asteroid’s apparent brightness. They should then be able to relate astronomers’ difficulty in finding new asteroids to the significant decrease in their brightness.

Seeing Circles—Studying Albedo

After the discovery of the four largest and brightest asteroids, nearly four decades passed before other asteroids were identified. The remaining asteroids were considerably smaller and dimmer, but other physical properties of asteroids also contributed to this lull in asteroid discovery. In addition to size, the shape of asteroids, the distance of their orbits from Earth, and their albedo (the reflectivity of their irregular surfaces) all made observing asteroids from Earth difficult.

In the “Seeing Circles—Studying Albedo” activity, students devise their own scale for making brightness comparisons. They will use solid circles of shades ranging from white to gray to black in order to construct their own “percentage of whiteness” scale, and then classify circles that are not solid shades based on this scale. This activity also provides students with some excellent background as they continue to explore reasons why suddenly, after such a long period when no discoveries were made, new asteroids were being found every year.

Where Are You?

Advances in telescope design and technology led to a flurry of asteroid discoveries between 1845 to1890. Nevertheless, even with the most powerful 19th century telescopes, larger asteroids only appeared as tiny points of light. The scale modeling activity, “Where Are You?,” will help students develop a perspective of the size and distance of two asteroids, Ceres and Vesta, in relation to Earth. In doing so, students will also appreciate the challenges faced by 19th century astronomers working with the limited technology available during that time.

Modeling in 3-D

Astronomers were not content, however, just to continue discovering “minor planets.” They wanted to know more about them—things like their shapes and sizes, their compositions, and their rotation rates. These types of observations, however, required new and better technology. In the latter part of the 19th century, photography and spectroscopic observations were being used to determine asteroid shape and the constituents of asteroid atmospheres.

In the hands-on activity “Modeling in 3-D,” students will use a series of two-dimensional images of Vesta, taken by the Hubble Space Telescope, to form clay models of the asteroid’s three-dimensional surface structure.

TEACHER GUIDE APPENDICES

- A list of standards addressed in this section of the module (**Appendix A)**
- Additional background resources—both online and print—for this module are provided in the Resource Section
- Visit the Dawn Dictionary for a list of terms and definitions for this module

Getting Started

You will find a separate Procedure section below for each of these activities, listing the *National Science Education Standards* addressed and the materials required. You will also find suggestions for:

1. introducing the activity;
2. implementing the activity; and
3. conducting follow-up and tie-in sessions.

MATERIALS

For the “mathematical” option

- Activity, “Patterns in the Sky, Part 1”
- Activity, “Patterns in the Sky, Part 2”
- Calculator

For the “active” modeling option

- Prepare labels for students that identify the planets they represent:

Sun	
Mercury	4 steps
Venus	7 steps
Earth	10 steps
Mars	
Jupiter	
Saturn	

  “Trial representatives” for Mars, Jupiter, and Saturn should have labels of 13 steps, 16 steps, and 19 steps respectively to give students a feel for where the asteroid belt is located.
- To use the more active modeling option, you will need a large enough area, either a large classroom, gymnasium, hallway, or outdoor space so that the distance from the Sun to Saturn can be equal to 100 steps.
- A large whiteboard, overhead projector, or poster paper for calculations

Teaching TIP

If your students do not have the algebraic skills necessary to complete the calculations required, conduct this activity as a guided inquiry class activity, as you carry out the mathematical calculations on an overhead transparency.

PROCEDURE for both options

1. Introduce either of the activity options by reminding students that scientists spend a good amount of time making careful observations of natural phenomena that often lead to discoveries.
   a) Ask the students who were assigned the flashback, “Thinking Outside the Box,” how many years Copernicus made astronomical observations before proposing his heliocentric model. [36 years]
   b) Ask the students who were assigned the flashback, “Between Jupiter and Mars.” how many years Tycho Brahe made measurements of planetary movements. [26 years]
2. Remind students that scientists often look for patterns in observed data to help explain it. In the “Patterns in the Sky” activity, students will model early scientists as they look at planetary distance data in much the same way that scientists did in the early 1700s.

PROCEDURE for mathematical option

The procedures for the active modeling option are in the section following these procedures.

1. Distribute the activity, “Patterns in the Sky, Part 1,” to each student. Direct students to read the first introductory paragraphs. Tell them that the table contains the distances from the Sun to each of the first three planets in our solar system.

2. Tell students to imagine that the distance from the Earth to the Sun could be divided into 10 equal sections. To illustrate this, draw a representation of this distance on the board (see diagram below).

INSTRUCTOR TIP

Possible method for students to use to determine how many sections would be from the Sun to Mercury and Sun to Venus.

Mercury:

$$\frac{149{,}600{,}000 \text{ km (Sun to Earth)}}{10} = \frac{57{,}910{,}000 \text{ km (Sun to Mercury)}}{M} =$$

$$149{,}600{,}000\ (M) = 57{,}910{,}000\ (10)$$

$$M = \frac{57{,}910{,}000 \text{ km } (10)}{149{,}600{,}000 \text{ km}}$$

$$M = 3.87$$

$$M \sim 4$$

Venus:

$$\frac{149{,}600{,}000 \text{ km (Sun to Earth)}}{10} = \frac{108{,}200{,}000 \text{ km (Sun to Venus)}}{V}$$

$$149{,}600{,}000\ (V) = 108{,}200{,}000\ (10)$$

$$V = \frac{108{,}200{,}000 \text{ km } (10)}{149{,}600{,}000 \text{ km}}$$

$$V = 7.23$$

$$V \sim 7$$

3. Ask students to use the distances to determine how many of these sections there would be from the Sun to Mercury (M) and then the Sun to Venus (V), to the nearest whole number. (Answers M=4, V=7).

4. Students should then look at the chart and determine the pattern. The following “Instructor Tip” shows one way to find the pattern (4+0=Mercury, 4+3=Venus, 4+6=10, 4+9=Mars, and so on). Then ask students to use this pattern to complete the second chart. Provide them with the mean distances from the Sun to Mars,

Jupiter, and Saturn. Finally, students should place the names in the chart (4= Mars, 5=____, 6= Jupiter, 7=Saturn). Distribute the activity, "Patterns in the Sky, Part 2."

5. Ask students to write what they think scientists at this time may have thought belonged at the 5 distance from the Sun. (Students might suggest a small or missing planet.) If students state that the asteroid belt is located at this distance, remind them that in the early 18th century, the asteroid belt was unknown.

6. Now, discuss with students the question "How did the discovery of the Titius-Bode law play a part in the Dawn mission?"

PROCEDURE for active modeling of "Patterns in the Sky"

1. Prepare labels for students representing the Sun and the planets. Locate a large enough area for the activity– in a large classroom, gymnasium, hallway, or outdoor area.

2. Introduce the activity by telling students, "In 1702, David Gregory wrote, '...supposing the distance of the Earth from the Sun to be divided into ten equal parts'. Let's take Gregory's suggestion and divide the distance from the Sun to the Earth into 10 equal parts."

3. Have the student representing the Sun stand in a specified location so that the distance from the Sun to Saturn can be equal to 100 steps. Tell the student representing the Earth to take 10 steps from the Sun.

4. Ask, "Does anyone know how many steps Mercury and Venus should take to be in their proper distances from the Sun?" (Accept answers.) Then ask Mercury to take 4 steps away from the Sun and Venus to take 7 steps from the Sun.

5. Ask students, "Do you see a mathematical pattern developing here?" (Accept their answers. They may answer that Venus is three steps farther from the Sun than Mercury and Earth is three steps farther from the Sun than Venus.)

6. Do you think that this pattern continues for the remainder of the solar planets?" [Accept their answers.]

7. If they agree that the pattern might hold, say, "Let's be space scientists and experiment." Then place "experimental representatives" for Mars, Jupiter, and Saturn at 13 steps, 16 steps, and 19 steps from the Sun.

8. Tell the "experimental students" to stay where they are and ask, "What would you have to know before you can determine whether or not these 'representatives' are the correct distances from the Sun?" [Accept their answers and continue to question until they ask for more data.]

9. Say, "Astronomers have actually measured the distances of Mars, Jupiter, and Saturn from the Sun. If we put them on the same scale, then <students labeled Mars>, you need to take 16 steps from the Sun; <student labeled Jupiter>, you take 52 steps from the Sun, and <student labeled Saturn>, you take 100 steps from the Sun."

10. Ask, “Was our original pattern correct?” (No) “Why do you think it was not correct?” (We did not have enough information.) “Now do you see a different mathematical pattern? If so, describe in your own words the pattern that you have found.” [Accept their answers.]

11. “If no one has found a pattern, we may need to do some more looking. Let’s record our data and look further.”

12. Continue to probe by saying, “We know that just adding 3 steps to Earth’s distance to locate Mars were not correct, but let’s take another look at these relationships:

    $4 + 0 = 4$
    $4 + 3 = 7$
    $4 + 6 = 10$

    What would follow?
    $4 + 12 = 16$ What planet did we find there? [Mars]
    $4 + 24 = 30$ Did we have a planet there? [No]
    $4 + 48 = 52$ What planet did we find there? [Jupiter]
    $4 + 96 = 100$ What planet did we find there? [Saturn]”

13. Wrap up the activity by asking questions similar to:

    a) If you were a scientist working during the 1700s and you knew the locations of the “classical planets” – Mercury, Venus, Earth, Mars, Jupiter, and Saturn [point to students representing these planets], what would you think about the missing planet at 30 steps that you discovered should be part of this pattern?

    b) What you have just discovered is now called the Titius-Bode law. This “law” was confirmed by the discovery of Uranus in 1791 by William Herschel. In our model, how many steps from the Sun would Uranus be? [$4 + 192 = 198$ or about 200 steps]

    c) How did the discovery of the Titius-Bode law play a part in the Dawn mission?

MATERIALS

For Part Two

- Activity, "In Search of…"
- Handout, "Star Map Quadrants"

PROCEDURE

1. Introduce the activity by reminding students that when scientists have a question, they often design a plan for trying to find the answer and they need certain equipment to carry out the plan.
    a) Ask the students who read either the flashback, "It Was a Dark and Starry Night," or the one entitled, "Seeing Faraway Things as Though Nearby"
        i. Who were the Celestial Police?
        ii. What was their plan for finding the missing planet between Jupiter and Mars?
    b) Ask the student who read "Seeing Faraway Things" what new equipment the Celestial Police used to carry out their plan.

ALTERNATE STRATEGY #1

1. Ask students what they do when they lose a very small item or something that is difficult to find, like a contact lens, a staple, or a small thumbtack.
2. Does whether or not you know something about the item's color, shape, or where it might have been lost make a difference in the method you use to search for the item? If you were looking at an asteroid through a telescope, what do you think you would see?
3. Would any of the search techniques students listed as answers to questions 1 and 2 have been useful to the early asteroid astronomers as they looked for "minor planets"? Why or why not?

2. As you distribute the activity, "In Search of…," explain to students that they will represent the "Celestial (sky) Police."

3. Assemble students into groups of four. Grouping two pairs together would work. Explain that each student will receive a star map displaying a quadrant of the sky for several nights.

4. They will use a blink test to find a missing planet. One student should be able to locate this planet by noting which dot moved in relation to the "stationary" stars.

5. When the student locates this star-like object, it will look like a dot or another star that moves. (This dot represents an approximate location of the asteroid Vesta during the spring of 2003.)

ALTERNATE STRATEGY #2

Carry procedure #1 a step farther by asking a volunteer to provide a small item that you will "lose" for them. Have the volunteer step out of the classroom for a few seconds while you place the object somewhere in the room that is not obvious but not impossible to find. Ask the volunteer to locate the object and then verbalize the characteristics of the object that helped him or her find it.

6. When several students have discovered the missing planet, ask questions similar to the following:
    a) What did you do after you made the discovery?
    b) Did you tell others or keep the discovery a secret?
    c) If you told others, how did they react? Did they believe you?
    d) Did they want proof? If so, what kind of proof?

    e) If you kept it a secret, why did you do so?
    f) Did you do anything further to validate your discovery?

7. Relate the answers to these questions to the reaction of scientists to discoveries by asking those students who read “It Was a Dark and Starry Night”:
    a) What was Piazzi’s first reaction when he discovered Ceres? [He thought he had discovered the “missing planet.”]
    b) To whom did Piazzi communicate his findings? [Bode and other colleagues]

8. Ask students who were assigned “Astronomical Serependipity” :
    a) Who discovered Vesta? [Olbers]
    b) How many other asteroids were discovered between 1801 and 1807? [a total of four]

9. Ask students whether or not they think the experimental plan of the Celestial Police was successful. Why or why not? [“Yes” answers might include that Piazzi, who was a member of the Celestial Police, found a moving body between Mars and Jupiter. “No” answers might include the rationale that Ceres, Vesta, Juno, and Pallas were not THE missing planet but rather asteroids.]

TIP

You may want to provide students with the distance of Vesta from the Sun (353,400,000 km). Students might be interested to discover that Vesta does not fall into place according to the Titius-Bode law as they learned in “Patterns in the Sky.”

10. Distribute a clean copy of the star map to each group. Ask the groups to trace the path of Vesta over the nights of this simulation.

11. Explain that Vesta is a very bright asteroid and is sometimes visible with the unaided eye. Explain that although Vesta is one of the brightest asteroids, it was not the first body discovered in the asteroid belt.

12. What part did the Celestial Police play in the Dawn mission?

MATERIALS
- Activity, "How Bright Are You?"
- Copy of flashback, "What Can You See With a Telescope?"
- Graph paper or electronic spreadsheet software

PROCEDURE
1. Distribute copies of the flashback, "What Can You See With a Telescope?" to students who were not assigned this reading during the Exploration session.

2. Introduce the activity by asking students what happens when scientists find that the methods they have used in the past are no longer useful. [Hopefully, they modify the old method or use a completely new one or maybe they design some new equipment to help them with their experiment.]

3. Ask students who have read flashbacks, "It was a Dark and Starry Night," "The Lost is Found," and "Astronomical Serendipity," to:
   a) List the names and dates of the first four asteroids discovered; and,
   b) Describe the method that was used to find these asteroids.

4. Ask students who have read flashback, "What Can You See With a Telescope?," to
   a) List some asteroid features that made further discovery of these "minor planets" difficult, if not impossible, for 40 years after the discovery of the first four asteroids. (Write the feature on the chalkboard or overhead transparency as students list them).
   b) Define or describe the feature and to clarify how this feature is important to the visual discovery of asteroids.

5. Continue by asking students to identify what methods astronomers were using during the period from 1807 to 1845. How were these methods similar to, or different from, the methods used to discover the first four asteroids? Why were these old methods not successful after 1807? You may have to refer these questions to students who were assigned the previous flashbacks.

6. Ask students why the brightness of an asteroid is such a critical factor when using a telescope for discovery. What factors contribute to the apparent brightness of an asteroid as viewed from Earth? (When using a telescope, you are seeing the amount of sunlight the asteroid reflects. An asteroid's apparent brightness depends upon its distance from the Earth, its position in its orbit, what part of its surface is facing the Sun, and the albedo of this reflecting surface.)

7. Distribute graph paper to each pair of students. Have them complete the activity "How Bright Are You?" in which they study the effects of asteroid brightness on the discovery process. Using the data in the table found in the flashback, "What Can You See With a Telescope?," have them graph the asteroid's apparent brightness versus the date of its discovery. Tell students to plot the points; they should not connect the points with a line.

8. Have students interpret the meaning of the plotted points, by completing the interpretation questions from the activity. Their answers should indicate their understanding of how the significant decrease in brightness related to astronomers' difficulty in finding these new asteroids. (Since brightness is measured on a negative scale, the line will have a positive slope, so students may need some help interpreting the graph. If they have had experience with exponential scales, such as those used in the Richter scale of earthquake intensity, you may want to indicate that a magnitude difference of 1.0 is equivalent to a 10-fold difference in magnitude.)

9. Complete the activity by telling students that scientists often
   a) organize data in table or graph form before trying to analyze it. Why do you think this is so? [At this point they ought to realize how much easier it was for them to analyze the information in table and graph form rather than in text form.]
   b) Then ask students why they think scientists develop scales like the brightness scale or the Richter scale. How are these types of scales helpful in organizing data? [comparisons of magnitudes are made more easily]

10. What role did the discoveries and properties of the early-discovered asteroids play in the planning of the Dawn mission?

MATERIALS

- Graph paper
- Activity, "Seeing Circles—Studying Albedo"
- Handout, "Ping Pong" (Use the version directly from your **printer**…For best results**, do not photocopy**)
- Polystyrene balls (different sizes and shapes)
- Flat gray paint
- String
- Lamp
- Protractor

PROCEDURE:

1. Introduce the activity by asking students who were assigned the "What Can You See With a Telescope?" flashback to recall what scientists can "see" when they look asteroids through a telescope. Ask questions like:
    a) What factors affect how much sunlight asteroids reflect to observers on Earth? [These factors include its size and shape, the type of surface features (color, reflectivity, number of craters), its rate of rotation, its distance from Earth, and its position in its orbit relative to the Sun]
    b) How do each of these factors affect how much reflected light scientists see through a telescope?
    c) If scientists were trying to discover the surface characteristics of an asteroid, which of the factors named would have the greatest effect? [Students may have different opinions about this so accept their answers so long they are scientifically accurate.]

2. Pick up on the opportunity to discuss the significance of the reflectivity factor when it is mentioned tby saying, "Let's learn a little more about what reflectivity really means." Distribute copies of the activity, "Seeing Circles—Studying Albedo," and the accompanying handout, "Ping Pong."

3. In Section A of the activity, you may have students describe what they know about how light interacts with other objects either as an individual pre-activity survey or as part of a class discussion.

Teaching TIP

During the pilot testing of this module the teacher needed to clarify the meaning of the term "interact" with students in grade seven.

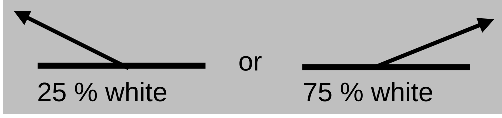
4. Students may arrange the circles of solid shades from the handout to form a "percentage of whiteness" scale as individuals, in pairs, or in small groups.

5. When students have completed their arrangements, call the class back together to make comparisons of the scales.
    a) Ask students if they see any differences in arrangements.

Teaching TIP

For younger students, in Section A, number 3 of the Student Activity Sheet have students use an arrow to show the percentage of whiteness.

For example:



   b) If there are differences in the arrangements, ask why they think there are differences.
   c) Ask if there is a right or wrong arrangement. Why or why not?
   d) Ask how students think that scientists might decide which of the "percentage of whiteness" arrangements should be the standard for use of all scientists.

6. Have students examine the "Albedo" chart on the second page of the activity sheet. Call their attention to the fact that the albedos shown in the chart are given in decimal fractions rather than in percentages. If necessary, show students how to change percentages to decimal fractions. Ask the following:
   a) Which objects in the chart reflect the most light? Which reflect the least light?
   b) Ask whether students can think of any objects that might have an albedo of 1.0. Are there any objects that might have an albedo of 0? (An object with an albedo of 1.0 reflects all the visible light that interacts with it. It is theoretically possible, but practically speaking, that probably won't happen. An albedo of 0 implies that the object absorbs all visible light that strikes it. There are some astronomers who think there may be black asteroids that would not reflect any visible light.)
   c) Ask why some of the objects have albedos that are ranges of numbers while others are single numbers. (Ranges of albedos occur when the objects' surface is not the same throughout.)

7. In Section B of the activity, students will use the same method they used for the circles of solid shades to arrange a second set of circles from the handout. Have them answer questions 1 and 2 of the activity in writing either for evaluation or to form the basis for a class feedback session.

8. Use question 3 of the activity to relate this activity to asteroid discovery by recalling that most asteroids have irregular surfaces with differing albedos. How would this feature make asteroids more difficult to discover using telescopes?

9. In question 4, students will write a definition of "albedo" in their own words, use "albedo" in a sentence, and draw a picture that is meaningful to them. Use students' descriptions of albedo to check for misconceptions of the term.

10. Give students ample time to construct and experiment with their asteroid models in Section C of the activity.

11. In Section C of the activity feedback session, ask students questions similar to the following:
    a) The polystyrene ball was the model for an asteroid. What was the lamp modeling? (the Sun)
    b) What did the person standing and looking represent? (A person making an observation from Earth)
    c) What effect did the angle of light source make when you were studying the surface of the asteroid model?
    d) What effect did the gray paint have on the reflectivity of the asteroid model surface?
    e) What effect did the deepness of the craters have on the reflectivity of the asteroid model surface? (deeper craters might mean that the surface reflectivity would be less)
    f) How would your image of an asteroid depend upon the angle from which you were viewing it?

g) How would your image of an asteroid depend upon the angle at which the light was shining on it?
h) What was the significance of making sure that your asteroid model was rotating during the last part of the activity?
i) What factors affect an image of an asteroid's surface as observed by an astronomer? (Make a class list of factors.)
j) What will scientists be able to learn from the Dawn mission about the surfaces of Ceres and Vesta that they have not been able to observe from telescopes here on Earth or from space telescopes like Hubble? (The instruments aboard the Dawn spacecraft will help scientists determine what chemical elements are found in the asteroids' surfaces, the asteroids' geological features, and whether the asteroids' surfaces are wet or dry.)

MATERIALS

For each team of four

Activity, "Where Are You?" (for each student)

Assortment of food items, particularly fruits and vegetables, from which students can select four food items to represent the following solar system bodies:

- Earth: melon (roughly 25.5 centimeters in diameter)
- Mars: grapefruit (approximately 13.6 centimeters diameter)
- Vesta: raisin (1 centimeter)
- Ceres: grape (approximately 2 centimeters)

Note: The raisin and grape provide another interesting parallel to Vesta and Ceres in that Vesta is believed to be dry and Ceres has wet conditions.

Meter sticks

Setting: To model the distance of planets and asteroids, students will need to work in a large open space such as a football field, gymnasium, cafeteria, or hallway.

PROCEDURE

1. Ask the students who read the flashback "What CAN You See With a Telescope?": "If a 19th century astronomer observed an asteroid through the most powerful telescope available during that time period, what would this asteroid look like?" Students will recall that asteroids appear as tiny points of light.

   Ask the students who read "I Can See You More Clearly Now" what additional surface features of Vesta the Hubble Telescope revealed to scientists. (exposed mantle, ancient lava flows, impact basins and a flattened side on Vesta.)
   Why do they think that Ceres' surface features are not very well-defined in Hubble images? (It was not close enough to Hubble at the time that it was being viewed.)

2. Now show them images of asteroids within star fields available at: http://www.brera.mi.astro.it/sormano/gallery/INDEX.html#Minor_planets (images captured from 1996 to 2003) or http://neo.jpl.nasa.gov/images/1999an10.html (taken in 1955). Point out to students that these asteroid images were captured fairly recently using much more sophisticated technology than was available during the 19th century.

3. Mention to students that even two of the largest and brightest asteroids, Vesta and Ceres, only appeared as points of light in the sky when using early Earth-based telescopes. Introduce the activity by explaining that Vesta is actually similar in size to the state of Arizona, while Ceres is comparable to the size of Texas. Explain that the model they will create in class will help them to visualize the size and distance of these two asteroids in relation to Earth.

4. Distribute the activity "Where Are You?" to each student.

5. Have a variety of food items of different sizes displayed in class. Some should fit the scaled-down diameters (25.5 cm, 13.6 cm, 2 cm, and 1 cm). Be sure to have other sizes

as well so that students must do the calculations to select the most appropriate food model.

6. Explain to students that they will convert the actual diameters of several planets and asteroids to reflect the scale of 1 cm = 500 km. Ask them to show their calculations and refer to the example given for Mercury. It may be necessary to calculate a few more examples with students, before they complete the table in Part 1 themselves.

7. Assemble students into groups of four. As they finish their calculations for Earth, Mars, Vesta, and Ceres, ask them to go to the food display and select the most appropriate representation.

8. Allow time for students to respond to the questions in Part 1. Then have students share their responses to questions 2, 3, and 4 with the class.

9. In Part 2 of this activity, students will create a scale model of the distances of Earth, Mars, Vesta, and Ceres. After students have reviewed the table and answered question number 5, spend some time discussing why it is difficult to create one scale model of the entire Solar System that reflects both size and distance.

10. Before students measure their stride and use it as a unit of measurement, it may be interesting to spark some discussion by getting students to think about how things become standards in measurements. Some historical examples can be found at: http://standards.nasa.gov/history_metric.pdf Students may find it fascinating, for instance, that King Henry I set the standard yard as the distance from the tip of his nose to the end of his outstretched thumb. You may also want to ask students who have played in a marching band to share their experiences with standardizing steps.

Alternative Strategy

Instead of students using their own strides to measure distance:

1) Designate one student's stride as the standard or

2) Have all students measure their individual strides, then use the class average as the standard.

11. To initiate a post-activity class discussion, use a format similar to a K-W-L Chart (Ogle, 1986). On a board, draw three columns and label with the following questions: *What do I know? What do I want to find out? How could scientists find out?* In the first column, ask students to list what they know about Vesta and Ceres from their modeling experiences. Then, get students to think about what questions they may still have about these two asteroids. List their unanswered questions in column two.

12. Finally, in the last column, students could share some possible technologies that might help astronomers seek answers. If students include the Dawn mission, ask them which of their unanswered questions in column two the instruments on the Dawn spacecraft might answer. If they haven't mentioned the Dawn mission, ask them what kind of instrumentation a spacecraft might carry that could answer some of their questions. Then compare their suggestions with the actual goals of the mission.

MATERIALS

For each individual or team

Activity, "Modeling in 3-D"
- Handout, "Hubble Space Telescope Images" (These images should come from http://neo.jpl.nasa.gov/images/vesta.jpg, an enlargement of the images from http://neo.jpl.nasa.gov/images/vesta.html)
- A ball of modeling clay or other moldable that is **approximately 10 cm in diameter**
- A protractor
- A metric ruler
- Toy top (optional)
- Classroom globe (optional)

For the classroom:
- A computer with Internet access and Quicktime movie capabilities

PROCEDURE

Introduce this activity by asking students about the making and use of scientific models. Why do scientists make models of objects? [Possible answers include:
- ➢ because they are too large or too small to be studied directly,
- ➢ because they are not accessible for study in the laboratory, or
- ➢ because we can only study topics indirectly.]

What kinds of models do scientists make? [If you have a physical model, such as one that includes the Earth, Moon, and Sun, hold it up for student observation. You might show students a mathematical model of wave motion (sunlight). Explain to students that they are going to make a 3-D model of the asteroid Vesta, based on the images of the asteroid that have been made by the Hubble Space Telescope.

1. Distribute copies of the activity, "Modeling in 3-D," and the handout, "Hubble Space Telescope Images of Vesta." Allow time for students to read the directions and ask questions regarding the activity.
   a) They may need some clarification about modeling "to scale." If you anticipate this, you could have a map with the scale marked on it to show students. Or, you could use a meter stick to measure the dimensions of the classroom and then make a scale drawing on the chalkboard or overhead transparency. Have students help decide what the scale will be.
   b) Most asteroids have irregular shapes, so most of them have at least a long axis and a short axis. The graphic in the activity indicates that the horizontal axis of this asteroid is longer than the vertical. To determine which of them is the axis of rotation, students will need to observe whether the structures or features move down from the top or from right to left as you go across the row of images. When they have determined that the vertical axis is the axis of rotation, you might wish to inform them that most asteroids rotate on their short axes.

Alternate Strategy Tip

- For procedure #2 on the activity sheet allow more advanced students to determine their own scale.

2. It is important that the students understand the concept of axis of rotation for procedure number 2 on the activity sheet. A good example of this is a top spinning on a table.

Show the top to the students and ask them to determine the axis of rotation. Use a classroom globe mounted on a stand to provide students with another example of axis of rotation. After showing these examples, elicit from students their definition of axis of rotation. Summarize by saying, “When something rotates, there will be a line where there is no movement; this is called the axis of rotation.” Explain to students that they will be attempting to identify the axis of rotation in their 3-D model of Vesta.

3. Tell students whether this activity will be done individually or in small groups of four students per group.

4. Indicate where students will find the clay, protractors, and rulers they will need to complete the activity. If students are working in groups of four, explain that they will each be working with one fourth of the asteroid. One person in the group should cut it into four equal parts.

5. Allow time for students to complete the activity. This may be more than one class period, so plan to store the models overnight in a place where they will not be tampered with.

6. When students have completed their models, ask them to recombine their quarter into one asteroid. Have students complete and share their answers to questions 6 and 7 in their activity sheet in a feed-back session.
   a) Do all their models look exactly alike? (There are probably similarities, but there will most likely be some differences.)
   b) How are they similar and how are they different? (Allow adequate time for students to make comparisons.)
   c) What could account for these differences? (These answers will vary with the students’ models.)
   d) Why was it important to construct your models to scale? (For one thing, it made comparisons easier, but more important, the models are more accurate.)
   e) Why do you think the amount and shape of Vesta’s visible surface changes as it rotates? (Vesta’s surface is not smooth or homogeneous. There are craters and surface areas made of different types of minerals, some of which may be from lava flows.)
   f) Vesta’s albedo is about 0.42. What does this mean? How does this physical characteristic of Vesta help scientists as they study the asteroid’s surface features? (An albedo of 0.42 means that Vesta’s surface reflects 42% of the sunlight striking it. This makes Vesta one of the brightest asteroids in the solar system and makes it easier for scientists to study its surface characteristics.)
   g) In what way(s) was it helpful to have multiple images of Vesta as you were making a physical model of the asteroid? In what way(s) might your physical model of Vesta have been different if you had only one image to work from? (Student answers will vary, but they will probably focus on the fact that, with only one image, they wouldn’t know what the other side of the asteroid looks like.)
   h) How do you think images from the Dawn spacecraft will help us learn more about Vesta’s surface and its internal composition? (Student answers will vary but you might want to guide them to thinking about how our understanding of the evolution of the moon’s surface was increased by seeing its surface up close and studying the moon rocks collected by the astronauts.)

Teacher Guide Appendices
for Development Section

APPENDIX A—STANDARDS ADDRESSED

National Science Education Standards addressed:

Science As Inquiry
Abilities Necessary to Do Scientific Inquiry

In "**How Bright Are You**?" students use graph paper and/or spreadsheets to graph the brightness of asteroids versus the dates of their discoveries. Students then interpret their graphs by studying the graph and looking for patterns and relationships of the data.

In "**Seeing Circles – Studying Albedo**" students use different objects (i.e., paper circles and Styrofoam balls) to learn about and model albedo. They discover the relationship that the rotation and surface features contribute to differences of albedo in objects on Earth and in space. Students make estimates of albedo both qualitatively and quantitatively.

In the activity "**Where Are You?**" students develop a model of asteroid diameters using mathematics and fruit. Students then use a different scale to determine relative distances to the asteroids by comparing the scale 1 AU = 20 meters.

In the activity, "**Modeling in 3-D,**" students develop a three-dimensional model of Vesta based on multiple two-dimensional images from Hubble Space Telescope. Students make measurements of dark and light areas in order to make their model as accurate as possible. Once complete, students compare their model (or part of the model) to others and to animations.

Science As Inquiry
Understandings about Scientific Inquiry

In the activity "**In Search of…**" students answer the question, "Can I find a "missing planet?" using a blink comparison using modern star charts or animation. Once students have found the missing planet, they will use their evidence to convince others of their finding. Questions in the teacher guide get students to think about the steps that happen after a discovery is made.

In the "**In Search of…**" activity students also learn about a team of "Celestial Police" who pool their talents and time in order to make systematic observations of the sky. Scientists in this group include: Zach, Lalande, Bode, Schroeter, Harding, Olbers, von Ende, Gildemeister, and Piazzi.

In "**Seeing Circles – Studying Albedo**" students begin by making observations of how light interacts with different shades of paper circles. From this initial study, students begin to learn and make operational definitions of "albedo." Students then transfer this knowledge in order to ask questions about the albedo of asteroids. Students then make models of asteroids using Styrofoam balls and a light source from different angles and then studying a model that rotates.

In the “**Where Are You**?” activity students come to realize that because of the great distances of Vesta and Ceres and their small size, it is necessary to employ technology in order to study them.

In the activity, “**Modeling in 3-D,**” students experience how models can be made to represent objects in space by making three-dimensional models based on two-dimensional images from the Hubble Space Telescope. In doing so, students will experience these images which show much more than a pinpoint of light.

Physical Science
Motion and Forces

In the “**Modeling in 3-D**” activity, students infer the rotation (movement) of Vesta based on multiple two-dimensional images.

Physical Science
Transfer of Energy

In “**Seeing Circles – Studying Albedo**” students observe how light reflects from objects of increasingly complex shades of whiteness and darkness. They organize these objects based on the reflectivity and develop an operational definition of “albedo.”

In the “**Modeling in 3-D**” activity, students observe light and dark areas on images of Vesta to infer motion. Students learn that the light areas are a result of reflected light.

Earth and Space Science
Earth in the Solar System

In the activity “**How Bright Are You?**” students learn about the discovery and brightness of asteroids identified from 1801 through 1849, and how these discoveries showed the increasingly complex nature of the solar system.

In the “**Where Are You?**” activity, students model the location of planets and asteroids in our solar system.

Based on observations of images of Vesta, students infer the motion of this asteroid in the activity, “**Modeling in 3-D**.”

History and Nature of Science
Nature of Science

In the “**Modeling in 3-D**” activity, students compare and evaluate the three-dimensional models of Vesta that the class made from two=dimensional images.

Science In Personal and Social Perspectives
Science and Technology in Society

While a new group of scientists looked for this missing planet, it was an Italian monk named Piazzi who finally discovered it in 1801, at an observatory in Sicily. Students learn about how Piazzi looked for the “missing planet” in the activity “**In Search of**…”. This discovery, which came to be known as an asteroid, would forever change our view of the solar system.