

The Solar System: Designing a Scale Model

Inquiries 3

Periods 4

CONCEPTS

Earth is the third planet from the Sun in the solar system.

The solar system—mostly empty space—includes the Sun, Moon, Earth, eight other planets and their moons, and smaller objects such as asteroids and comets.

A model is a representation—often mathematical—that helps demonstrate how complex processes, systems, and devices look and act.

Scale is a ratio between two sets of measurements. When the scale factor is known, scale measurements can be calculated from true measurements, and vice versa.

A scale model is one way of working with measurements that are too large to see firsthand.

Mathematics is an important tool for all aspects of scientific inquiry.

STUDENT OBJECTIVES

Brainstorm what students know and want to learn about the order and sizes of the planets and their distances from each other.

Create a model of the solar system from a set of scaled items.

Use scale models to explore the relative diameters of and distances between the nine planets and the Sun.

Summarize and organize information about Mercury.

OVERVIEW

This lesson is the first in a series on the solar system and serves as an assessment of students' current knowledge of the relationships among the planets, moons, and asteroids. Students begin by sharing and demonstrating what they know about the relative order and size of the planets and their distances from each other. Students use the diameters of the planets and the distances between them to create a scale model of the solar system. By making both qualitative and quantitative comparisons of the planets during this lesson, students prepare for later lessons in which they study other planetary characteristics, including geological processes, orbital motion, and tidal effects.

BACKGROUND

Our Sun is an ordinary star and is one of the millions of stars in the Milky Way Galaxy. Yet the Sun is surrounded by a system of nine planets (most of which have moons) and by a vast number of asteroids and comets. Astronomers believe that the planets, comets, and asteroids were natural by-products of the formation of the Sun.

Birth of the Sun

The Sun was formed about 4.6 billion years ago from a rotating interstellar cloud of hydrogen and helium gas. A thin, cold, rotating disk of dust and a large, spherical layer of gas surrounded this cloud. Under the force of its own gravity, the cloud shrank. As it shrank, it got hotter and began to spin faster. In very basic terms, the inner portion eventually coalesced into the Sun, leaving dust, ice, and gas, which formed into millions of small bodies that eventually collided and merged to form the planets.

Formation of the Planets

Gravity continued to shrink the central portion of the rotating cloud even more, and it became hot enough to cause **nuclear fusion**—the joining of hydrogen atoms to create helium. This fusion released energy in the form of a blast of radiation that stripped smaller bodies near the Sun of their gases; the more distant bodies were massive enough and far enough away from the Sun to retain their gases. As a result, the **terrestrial planets** closest to the Sun—Mercury, Venus, Earth, and Mars—formed as small, rocky bodies with little or no atmosphere, while the **gaseous planets**—Jupiter, Saturn, Uranus, and Neptune—formed as large, gaseous bodies with small rocky or metallic cores.

Formation of Moons

The gravitational force of the Sun was too strong to allow the closer planets to hold on to satellites (moons). However, the larger outer planets had sufficient gravitational pull to attract more matter and, as a result, these gaseous giants have extensive satellite systems. The inner moons in these systems are typically rocky and dense, while their outer moons are icy and less dense. Over time, some satellites have escaped the gravitational pull of their planets. Earth collided with another solar system body to form its moon. Mars captured two minor solar system bodies which became its moons.

Formation of Asteroids

Asteroids are rocky and metallic solar system bodies that orbit independently around the Sun. These objects are too small to be considered planets, but are often called “minor planets.” Many asteroids are located between Mars and Jupiter in what is commonly called the **asteroid belt**. These asteroids were formed from matter remaining after creation of the other bodies in the solar system. They were prevented by Jupiter’s gravitational pull from forming into planets. In the early days of the solar system, Jupiter’s gravitational pull diverted many asteroids into planet-crossing orbits, causing collisions between asteroids and planets that

resulted in intense cratering of planetary surfaces and the breakup of larger asteroids in the belt.

Scale Models

Students often are exposed to the solar system through photographs and other models. A **model** is a representation—often mathematical—of a process, system, or device. Models help demonstrate how complex systems appear and behave. A model often is used to represent something that is too large, too complex, too small, or too far away to be studied easily in a lab or classroom. A **scale model** is a two- or three-dimensional replica in which each element is shown in correct proportion.

Scale is a ratio between two sets of measurements. In this lesson, the term “scale” is used to describe the ratio between the size of, or distance between, bodies in the *model* solar system and the size of, or distance between, the bodies in the *actual* solar system. Students use scale as a guide to the relationship between the actual solar system and their representative solar system models or drawings.

During Lesson 2, students used Earth’s diameter as a unit to describe the distance from Earth to the Moon (“The Moon is 30 Earth diameters away from Earth.”) and to describe the diameter of the Sun (“The Sun is 109 Earth diameters across.”). Scientists often use the **astronomical unit (AU)**—the distance from the center of Earth’s mass to the center of the Sun’s mass, or 149.6 million km—to describe distances within the solar system. Since the diameters and distances within the solar system are so vast, a fixed point of reference makes large numbers more manageable.

A **scale factor (sf)** involves reducing all measurements by the same amount in order to achieve the measurement of the scale model. Once scientists determined the distance of the AU, they could determine the scale factor of the solar system and calculate the remaining distances to the planets by dividing each planet’s distance to the Sun by approximately 150 million km, or 1 AU.

A simple scale factor can be used to calculate the relative size and distance of planets: 1 cm = 10,000 km. Given the diameter of Earth, which is 12,756 km, the scaled diameter of Earth would be

approximately 1.3 cm. The calculation of the scale of Earth's diameter given a scale factor 1 cm = 10,000 km, involves the use of a ratio or the algebraic process of cross multiplication, as follows:

$$\text{Scaled Diameter (SD)} : \text{Actual Diameter (AD)} = 1 \text{ cm} : \text{scale factor (sf)}$$

$$\frac{\text{Scaled Diameter (SD)}}{\text{Actual Diameter (AD)}} = \frac{1 \text{ cm}}{\text{scale factor (sf)}}$$

$$\frac{\text{SD}}{\text{AD}} = \frac{1 \text{ cm}}{\text{sf}}$$

$$\text{SD} \times \text{sf} = \text{AD} \times 1 \text{ cm}$$

$$\text{SD} \times \text{sf} = \text{AD} \times \text{cm}$$

$$\text{SD} = \frac{\text{AD} \times \text{cm}}{\text{sf}}$$

or

$$\text{SD} = (\text{AD} \div \text{sf}) \times \text{cm}$$

$$\text{SD} = \text{AD} \div \text{sf}$$

Example:

$$\frac{\text{SD}}{12,756 \text{ km}} = \frac{1 \text{ cm}}{10,000 \text{ km}}$$

$$\text{SD} \times 10,000 \text{ km} = 12,756 \text{ km} \times 1 \text{ cm}$$

$$\text{SD} \times 10,000 \text{ km} = 12,756 \text{ km} \times \text{cm}$$

$$\text{SD} = \frac{12,756 \text{ km} \times \text{cm}}{10,000 \text{ km}}$$

$$\text{SD} = (12,756 \div 10,000) \times \text{cm}$$

$$\text{SD} = 1.2756 \text{ cm}$$

$$\text{SD} \approx 1.3 \text{ cm}$$

This means that to obtain the scaled diameter, students would divide the actual diameter by the scale factor and multiply by 1 cm (scaled diameter = actual diameter \div scale factor, or scaled diameter = $12,756 \text{ km} \div 10,000 \text{ km} \times 1 \text{ cm} = 1.2756 \text{ cm}$ or approximately 1.3 cm).

The distance from Earth to the Sun is 149,600,000 km, or a scaled distance of approximately 15,000 cm, or 150 m. The scaled distances and diameters of the other planets are

shown in Table 11.1: Using a Scale Factor. Because of its simplicity, this model is used during Inquiry 11.2 as a tool to help introduce students to methods for calculating scale factors. Inquiry 11.3 is for more advanced students and builds on this activity; it can be used with students who are experienced in creating models to scale. Appendix F: Studying Scale, can serve as an introductory lesson on scale if this concept is new to your students.

Table 11.1 Using a Scale Factor

Scale: 1 cm = 10,000 km

| Planet | Actual Diameter (km) | Scaled Diameter (cm) | Actual Distance from Sun (km) (AU = 1 Earth distance) | Approximate Scaled Distance from Sun (cm) |
|---------|----------------------|----------------------|--|---|
| Mercury | 4878 | 0.5 | 57,900,000 km (0.387 AU) | 5790 cm \approx 58 m |
| Venus | 12,102 | 1.2 | 108,200,000 km (0.723 AU) | 10,820 cm \approx 108 m |
| Earth | 12,756 | 1.3 | 149,600,000 km (1.0 AU) | 14,960 cm \approx 150 m |
| Mars | 6792 | 0.7 | 228,000,000 km (1.52 AU) | 22,800 cm \approx 228 m |
| Jupiter | 142,980* | 14.3 | 778,400,000 km (5.20 AU) | 77,840 cm \approx 778 m |
| Saturn | 120,536* | 12.1 | 1,426,700,000 km (9.54 AU) | 142,670 cm \approx 1.4 km |
| Uranus | 51,118* | 5.1 | 2,866,900,000 km (19.2 AU) | 286,690 cm \approx 2.9 km |
| Neptune | 49,528* | 5.0 | 4,486,100,000 km (30.0 AU) | 448,610 cm \approx 4.5 km |
| Pluto | 2340 | 0.2 | 5,890,000,000 km (39.4 AU) | 589,000 cm \approx 5.9 km |

*Not including rings

STUDENT MISCONCEPTIONS

Inaccurately scaled models or photos of the solar system often create misconceptions. Two examples are the following:

- Students often think that the planets are relatively similar in size to the Sun and are relatively close in distance to one another. (The diameters of the planets are vastly different. The distances between the last five planets are much greater than the distances between the first four planets.)
- Students may believe that the planets are always lined up with each other in the solar system. (Although nearly all of the planets orbit the Sun along the same plane of the ecliptic, they are not normally in alignment with each other because their orbital velocities and orbital periods vary.)

In this lesson students learn that there are disadvantages to having accurately scaled models, such as not having enough room to scale the models by distance. Make sure that you discuss why some models, such as tabletop models of the solar system, are inaccurately scaled.

READING SELECTIONS

In this lesson students examine photographs of two models—the orrery and the astrarium. In “The Orrery: A Model of the Solar System,” students read about George Graham’s first mechanical model of the solar system in which he duplicated the positions of the Sun, planets, and moons. In “An Astrarium: A Clock Without a Tock,” students read about the first mechanical device to track the changing positions of the Moon, Sun, Earth, and five other planets—Mercury, Venus, Mars, Jupiter, and Saturn. Students also read about Mercury in “Mission: Mercury.”

MATERIALS FOR LESSON 11

For the teacher

- 1 transparency
- 1 set of fine-point transparency markers
- 1 black permanent marker

MATERIALS FOR INQUIRY 11.1

For the teacher

- Masking tape*
- Map with scalebar*
- Sample models*

For each student

- 1 copy of Student Sheet 11.1: Our Solar System Model*

For each group of 4 students

- 1 large resealable plastic bag labeled “11.1” containing the following:
 - 2 rubber balls
 - 2 Ping-Pong balls
 - 2 plastic buttons
 - 2 marbles
 - 2 acrylic beads
 - 2 wood barrel beads
 - 2 fishing bobbers
 - 3 split peas
 - 3 pieces of round oat cereal
- 1 adding machine tape, 6 m
- 1 marker*

MATERIALS FOR INQUIRY 11.2

For the teacher

- 1 transparency of Student Sheet 11.2: Using a Scale Factor*
- 1 copy of Inquiry Master 11.2: Using a Scale Factor (Answer Key)

*Needed, but not supplied

For each student

- 1 copy of Student Sheet 11.2: Using a Scale Factor*
- 1 calculator (optional)*

MATERIALS FOR INQUIRY 11.3**For the teacher**

- 1 transparency of Student Sheet 11.3a: Calculating the Scale Factor*
- 1 copy of Inquiry Master 11.3a: Calculating the Scale Factor (Anticipated Responses)
- 1 transparency of Student Sheet 11.3b: Calculating Scaled Distance*
- 1 copy of Inquiry Master 11.3b: Calculating Scaled Distance (Anticipated Responses)
- 1+ trundle units (optional)*
- Clear packaging tape (optional)*

For each student

- 1 copy of Student Sheet 11.3a: Calculating the Scale Factor*
- 1 copy of Student Sheet 11.3b: Calculating Scaled Distance*
- 1 working copy of Student Sheet 10.1c: Planetary Chart*

For each group of 4 students

- 1 small resealable plastic bag labeled “11.3” and containing the following:
 - 2 small beads, 0.2 cm
 - 2 peppercorns, 0.46 cm
 - 1 rubber ball, 5.5 cm
 - 1 fishing bobber, 4.6 cm
 - 2 acrylic beads, 1.7 cm
 - 1 straight pin with round head
- 1 metric ruler, 30 cm (12 in.)
- 1 metric measuring tape
- 1 Planet Data Card Set (set of 9)**
- 1 calculator*

*Needed, but not supplied

**The module kit contains 8 sets of 9 Planet Data Cards. The planet name is located on one side of the card in large font; planet data is on the reverse side.

PREPARATION

1. Cut a 6-m strip of adding machine tape for each group and a few additional strips.
2. Place each group’s items for Inquiry 11.1 in a large resealable bag. Label the bags “11.1.” Place each bag in a plastic box, along with a strip of adding machine tape and a marker. These bagged materials can be reused by other class periods and from year to year.
3. Place a 20-cm strip of masking tape across each group’s plastic box lid. Students can use the tape to keep their adding machine paper in place when conducting Inquiry 11.1.
4. Review Inquiry 11.3, which is a more complex mathematical inquiry than Inquiry 11.2. Students create a solar system model that is to scale for both size and distance. To complete the second half of Inquiry 11.3, you will need access to a large gymnasium, hallway, or athletic field. You may want to complete this inquiry, as well as the optional Appendix F: Studying Scale, in conjunction with your school’s mathematics department.
5. Place the materials for Inquiry 11.3 in small resealable plastic bags. Label the bags “11.3” and set them aside. Do not put them in the plastic boxes until Inquiry 11.3 begins. Keep in mind the following:
 - The tip of the pin is used to model the size of Pluto. This pin may be hard to keep track of. To more easily identify the pin, wrap masking tape around the shaft of the pin.
 - The small beads are used to model Mercury and Mars. The peppercorns are used to model Earth and Venus. Consider placing each small item between two pieces of clear packaging tape or on a piece of masking tape to prevent groups from misplacing them.
 - The rubber balls, fishing bobbers, and acrylic beads are used in Inquiries 11.1 and 11.3; however, the module kit contains

enough materials for you to prepack and label the materials bags for both inquiries simultaneously.

Getting Started

1. Invite students to record what they already know about the order of, size of, and relative distances between planets within the solar system. Invite students to share their notebook entries. You may want to record their ideas on a transparency.
2. Show students the map and the sample models you have collected. Point out the scalebar on the map. Assess students' prior knowledge of scale by asking them questions such as the following:

What does the term "scale" mean when used with maps?

What is a model? What are some examples of models?

Why is it important to build models to scale?

When is it difficult to build models to scale?

What do you think a scale model of the solar system should look like?

3. Review the objectives of the lesson with the class. Let students know that they will design and build a model of the solar system in this lesson.

Inquiry 11.1 Designing a Model Solar System

PROCEDURE

1. Review with students the concept of converting millimeters to centimeters. Use a split pea as an example, which measures approximately 4 mm, or 0.4 cm.
2. Review the Inquiry 11.1 procedures with students and discuss how students will record their data. (You may prefer that students record their work in their science notebooks rather than on Student Sheet 11.1. A sample student notebook entry is shown in Figure 11.1.)



Figure 11.1 A list of the planets in order and various objects that model the planets, their diameters, and distances, as recorded by one student in her science notebook

3. Have students conduct Inquiry 11.1. Provide groups with more adding machine tape as needed. Point out that students can use the strip of masking tape to keep their adding machine paper in place on the floor. Remind students to complete Table 1 and to draw a picture of their model, either on Student Sheet 11.1 or in their notebook.

D. Do you think the objects in your model are to scale in terms of size? Why or why not? (Use this question to assess students' understanding of scale in terms of "relative size.")

E. Do you think the objects in your model are to scale in terms of distance? Why or why not? (Use this question to assess students' understanding of scale in terms of "relative distance.")

REFLECTIONS

1. Invite groups to share their solar system models. Ask them to defend their selections and the placement of their models.

2. Ask students to answer the following questions in a class discussion as you examine their models (you also may ask students to record them in their science notebooks):

A. What was the largest planet in your model? What was the smallest planet? (Use this question to assess students' understanding of the relative sizes of the planets.)

B. Do you observe any patterns in the sizes of the planets in your model? If so, what are they? (Students may have displayed pairs of planets that are similar in size. For example, Mercury and Mars, Venus and Earth, and Uranus and Neptune. Others may have displayed the terrestrial planets as smaller than the gaseous planets.)

C. Do you observe any patterns in the distances between your planets in your model? If so, what are they? (Students may note that the inner planets are closer to one another than the outer planets. Some students may have created a space between their Mars and Jupiter to show the asteroid belt.)

Inquiry 11.2 Using a Scale Factor

PROCEDURE

1. Introduce students to the term "scale factor" by asking them to examine SG Figure 11.1 and to consider this simplified example: How big would the model of a school bus 10 m long be if the scale factor that was used to make the model bus was 1 cm = 2 m?

2. Set up the relationship for students by showing them the following equation:

$$\frac{x}{10 \text{ m}} = \frac{1 \text{ cm}}{2 \text{ m}}$$

$$x \times 2 \text{ m} = 10 \text{ m} \times 1 \text{ cm}$$

$$x \times 2 \text{ m} = 10 \text{ m} \times \text{cm}$$

$$x = \frac{10 \text{ m} \times \text{cm}}{2 \text{ m}}$$

$$x = 5 \text{ cm}$$

Help students understand that by dividing the actual size of the bus by the scale factor (2 m) and then multiplying the answer

by 1 cm, they can calculate the size of the model. The model bus would be 5 cm long. Have them define the term “scale factor” in their notebooks.

NOTE When teaching proportions, it is best to show all the equal ratios and to encourage students to practice labeling what is being compared. For example, students can show proportionality, such as “cm:m = 1:2 (scale model) = X:10 (actual).” Or, students can use an algebraic process of cross multiplication. Appendix F: Studying Scale can be used if the concept of scale is new to your students.

3. Ask students to calculate the scaled diameter (SD) of Earth with a scale factor of 1 cm = 10,000 km. Using the relationship similar to the one in Procedure Step 2, help students divide the actual diameter of Earth (12,756 km) by 10,000 km, and then multiply that number by 1 cm. (See the ratio shown in SG Procedure Step 4.) Students should calculate the approximate SD of Earth as 1.3 cm. (See Table 11.1 in the Background for the calculated scaled diameters and distances of all nine planets using this scale factor.)
4. Distribute Student Sheet 11.2. Ask students to review the actual diameters and distances of the planets listed in Table 1: Using a Scale Factor. Use proportionality or an algebraic process of cross multiplication to review how the formulas in each column on the student sheet were derived. Set up the relationship for students by showing them the following equation:

Scaled Distance (SDs) : Actual Distance (ADs) =
1 cm : scale factor (sf)

$$\frac{\text{Scaled Distance (SDs)}}{\text{Actual Distance (ADs)}} = \frac{1 \text{ cm}}{\text{scale factor (sf)}}$$

$$\text{SDs} \times \text{sf} = \text{ADs} \times 1 \text{ cm}$$

$$\text{SDs} \times \text{sf} = \text{ADs} \times \text{cm}$$

$$\text{SDs} = \frac{\text{ADs} \times \text{cm}}{\text{sf}}$$

or

$$\text{SDs} = \text{ADs} \div \text{sf}$$

5. Have students complete Student Sheet 11.2 by recording their calculations in the appropriate columns. Encourage students to show all work.

REFLECTIONS

1. Discuss Inquiry 11.2 with students. Use a transparency of Student Sheet 11.2: Using a Scale Factor as your guide.
2. Ask students to independently answer the following questions in their notebooks, and then discuss them with the class:
 - A. How close was your model during Inquiry 11.1 to the scaled model calculated during Inquiry 11.2?
 - B. Does anything about your calculations on Student Sheet 11.2 surprise you? Explain.

Inquiry 11.3

Building a Scale Model of the Solar System

PROCEDURE

1. Distribute one resealable bag of items labeled “11.3” to each group. Let students know that these items *are* to scale with the actual diameter measurements of the planets.
2. Invite groups to position the items so that they represent the size of the nine planets, but remind them not to consider distance at this point. (See the third column of Table 1 on Inquiry Master 11.3a for possible responses.)
3. Distribute Student Sheet 11.3a. Have students calculate the scale factor for each planet in their model. (See Inquiry Master 11.3a for anticipated responses. Recommend that students use the Materials List for Inquiry 11.3 for specific diameters of each object.) Students’ answers may vary slightly if they have measured the diameters on their own. Students then calculate the average of their results, which is the approximate scale factor for their entire model solar system.
4. Invite students to share their results. Use a transparency copy of Student Sheet 11.3a to calculate a class average. (Students should compute, on average, a scale factor of 1 cm = 27,755 km or 1: 27,755. See Inquiry Master 11.3a for an anticipated average.)
5. Explain to students that a true model of the solar system is to scale not only in terms of diameter but also in terms of distance. Distribute a copy of Student

Sheet 11.3b to each student. Working in groups, have students use the actual distances of the planets and the scale factor they calculated on Student Sheet 11.3a (for example, 1 cm = 27,755 km or 1: 27,755) to determine how far from a model Sun to place each scaled planet to create an accurate scale solar system model for both size and distance. Give groups time to make their calculations. (See Inquiry Master 11.3b for possible responses. Students’ answers may vary slightly, based on their scale factor.)

NOTE Point out to students that each answer for scaled distance on Student Sheet 11.3b will be in centimeters, but that they will have to convert their answers to either meters or kilometers to make the measurements more meaningful. (To convert centimeters to meters, have students divide the number of centimeters by 100, since 100 cm = 1 m. To convert centimeters to kilometers, divide the number of centimeters by 100,000, since 100 cm = 1 m and 1,000 m = 1 km.)

6. If possible, take students to a long hall or gymnasium or—ideally—outdoors to an athletic field. Each group will need one copy of the completed Student Sheet 11.3b and bag “11.3” of planet objects. Take along one set of Planet Data Cards for the class. Do the following:
 - Assign a different planet to each group.
 - Provide each group with one copy of the appropriate Planet Data Card.
 - Designate an item in the area (for example, a wall or a goal post) to represent the Sun.
 - Using the students’ calculations from Inquiry 11.3, have each group step out the scaled distance for its assigned

planet. Have students estimate the distances using one giant step for 1 m, or use a trundle unit from the math department if it is available.

- Go out as far into the solar system model as you can. You may need to stop at either Mars or Jupiter if your space is limited. (Inform students that in this scale model, Pluto would nearly be 2.1 km, or 1.5 miles, away!)
- When each group is in position, have them hold up their model planet and its name card.
- If possible, position Planet Data Cards and model planets at the appropriate distances along the halls of your school or along a football field.

REFLECTIONS

1. Ask students to answer the following questions in their notebooks, and then discuss them as a class:

A. What observations and comparisons can you make about your model? (Answers will vary. For example, students may note that there were planetary “pairs” with similar sizes, such as Venus and Earth, Neptune and Uranus, and Mars and Mercury.)

B. How does Earth compare with other planets in size and distance from the Sun? (Earth is similar in size to Venus. It is smaller than all of the gaseous planets, but it is larger or equal in size to the other terrestrial planets. It is larger than Pluto and is the third-closest planet to the Sun.)

C. How is your model different from the actual solar system? (The actual sizes

and distances of the planets in the model have been reduced by the scale factor. The appearance of the model planets does not resemble the appearance of the planets. Also, the planets in the model are more or less in a straight line, but in the real solar system, they are not.)

D. How is your model similar to the actual solar system? (Students may say that the planets are in the correct order and that the sizes of the planets are proportional, as with the actual solar system. Other than Pluto, the planets are also in the same plane, as they probably are in the students’ model.)

E. What is the relationship between the diameter of the planets and their positions from the Sun? (Students may note that the smaller planets, except Pluto, are closer to the Sun, while the larger planets are farther from the Sun.) What reasons do you have for your answer? (Most students may not realize at this point that the gaseous atmospheres of the larger gaseous planets are considered part of their diameters—although the rings often are not. See the Background for information as to why the smaller bodies near the Sun were stripped of their gases.)

F. Analyze Table 1 on Student Sheet 11.3b. How do the distances between the first four planets compare with the distances between the other planets? (The terrestrial planets are spaced evenly, as are the gaseous planets; but the terrestrial planets are closer together. Students also may note that there is a great distance between Mars and Jupiter. This is where the asteroid belt is located.) What reasons do you have for your answer? (The gaseous planets are so massive that they may have taken any nearby solar system bodies into their gravitational forces as satellites.)

G. Think back to “Getting Started.” How is your final solar system model different from your earlier statements about what a model of the solar system looks like? (Answers will vary, but most students will admit that the distances between the planets in an accurately scaled model are much greater than most models of the solar system they may have seen.)

2. Distribute a set of Planet Data Cards to each group. Ask groups to examine the planetary distances and to determine what units are used to describe this value (AU and km). Invite students to brainstorm about what AU means.
3. Have students use their calculators to determine how the AU for each planet was calculated. Let students try this on their own first. They should determine, through trial and error, that by dividing each planet’s distance in km by its AU distance, that the quotient for each planet will be the same—149.6 million km. Ask students what this number represents. (It is the distance from the center of Earth’s mass to the center of the Sun’s mass.) Tell students that AU, or Earth’s distance to the Sun, is the scale factor most often used when describing planetary distances.

NOTE The exact planetary distance from the Sun in km is not given on the planet data cards for Saturn, Uranus, Neptune, and Pluto. For these exact distances, students should refer to Student Sheet 11.3b.

4. Have students read “The Orrery: A Model of the Solar System.” Encourage students to think about their observations of the solar system model.

5. Have students read “Mission: Mercury.” Remind students to record information from this reader onto Student Sheet 10.1c: Planetary Chart. If Mercury is their assigned planet for the Anchor Activity, students also should record information from this reader onto their copy of Student Sheet 10.1b: Planetary Brochure Outline.

HOMework

Students can complete the calculations for Student Sheets 11.2, 11.3a, and 11.3b for homework if they do not have enough time to finish them in class.

EXTENSIONS

■ History ■ Language Arts

1. Have students read “The Astrarium: A Clock Without a Tock.” How did the astrarium track the changing positions of the Moon, Sun, Earth, and planets? Why were only five planets displayed on the clock? Students can research to find out more about the astrarium.

■ Instructional Technology ■ Mathematics

2. Challenge students to find an Internet site that allows users to calculate scale online.

■ Art

3. Students can create accurately scaled models of the planets using modeling clay or styrene spheres. Encourage students to research various features of each planet and to paint the surface of the planet using accurate colors.

ASSESSMENT

Use this lesson to assess students' current understanding of scale. Use Student Sheet 11.2: Using a Scale Factor to assess their ability to convert actual measurements to scaled measurements using a scale factor.

PREPARATION FOR LESSON 12

Review Lesson 12. You may want to set up the plastic boxes with sand, flour, and cocoa in advance to save preparation time on the day of the lesson. Students may require lab coats, aprons, or tee shirts to protect their clothing from the flour and cocoa during the inquiries. Plan accordingly.

PREPARATION FOR LESSON 14

Review Lesson 14. You will need to collect 36 cans of non-diet soda—32 empty and 4 full—for Lesson 14. It is important to use non-diet sodas of the same brand. (Diet sodas weigh less than regular sodas due to lower sugar content.) You will fill the empty cans with varying amounts of sand to simulate the weight of a can of soda on the surface of each planet. The can representing Jupiter will be filled with large metal washers instead of sand. See the Preparations for Lesson 14 for more information. The 36 cans will accommodate four groups of eight students. If you wish to have fewer students in each group, increase the number of cans as needed.

SAMPLE

Inquiry Master 11.2

Using a Scale Factor (Answer Key)

Scale Factor: 1 cm = 10,000 km

Table 1 Using a Scale Factor (Answer Key)

| Planet | Actual Diameter (AD) (km) | Scaled Diameter (SD) (cm) SD = AD ÷ Scale Factor (sf) | Actual Distance from Sun (ADs) (km) | Scaled Distance from Sun (SDs) (cm) SDs = ADs ÷ sf |
|----------------|---------------------------|---|-------------------------------------|---|
| Mercury | 4878 | SD = 4878 km ÷ 10,000 km/cm SD = 0.49 cm ≈ 0.5 cm | 57,900,000 | SDs = 57,900,000 km ÷ 10,000 km/cm SDs = 5790 cm ≈ 58 m |
| Venus | 12,102 | SD = 12,102 km ÷ 10,000 km/cm SD = 1.21 cm ≈ 1.2 cm | 108,200,000 | SDs = 108,200,000 km ÷ 10,000 km/cm SDs = 10,820 cm ≈ 108 m |
| Earth | 12,756 | SD = 12,756 km ÷ 10,000 km/cm SD = 1.28 cm ≈ 1.3 cm | 149,600,000 | SDs = 149,600,000 km ÷ 10,000 km/cm SDs = 14,960 cm ≈ 150 m |
| Mars | 6792 | SD = 6792 km ÷ 10,000 km/cm SD = 0.68 cm ≈ 0.7 cm | 228,000,000 | SDs = 228,000,000 km ÷ 10,000 km/cm SDs = 22,800 cm ≈ 228 m |
| Jupiter | 142,980 | SD = 142,980 km ÷ 10,000 km/cm SD = 14.3 cm | 778,400,000 | SDs = 778,400,000 km ÷ 10,000 km/cm SDs = 77,840 cm ≈ 778 m |
| Saturn | 120,536 | SD = 120,536 km ÷ 10,000 km/cm SD = 12.05 cm ≈ 12.1 cm | 1,426,700,000 | SDs = 1,426,700,000 km ÷ 10,000 km/cm SDs = 142,670 cm ≈ 1427 m ≈ 1.4 km |
| Uranus | 51,118 | SD = 51,118 km ÷ 10,000 km/cm SD = 5.11 cm ≈ 5.1 cm | 2,866,900,000 | SDs = 2,866,900,000 km ÷ 10,000 km/cm SDs = 286,690 cm ≈ 2867 m ≈ 2.9 km |
| Neptune | 49,528 | SD = 49,528 km ÷ 10,000 km/cm SD = 4.95 cm ≈ 5.0 cm | 4,486,100,000 | SDs = 4,486,100,000 km ÷ 10,000 km/cm SDs = 448,610 cm ≈ 4486 m ≈ 4.5 km |
| Pluto | 2340 | SD = 2340 km ÷ 10,000 km/cm SD = 0.23 cm ≈ 0.2 cm | 5,890,000,000 | SDs = 5,890,000,000 km ÷ 10,000 km/cm SDs = 589,000 cm ≈ 5890 m ≈ 5.9 km |

Inquiry Master 11.3a

Calculating the Scale Factor (Anticipated Responses)

Table 1 Calculating the Scale Factor (answers may vary)

| Planet | Actual Diameter (AD) (km) | Scaled Object | Scaled Diameter (SD) (cm) | Scale Factor (sf) (km/cm) sf = AD ÷ SD |
|---|---------------------------|----------------|---------------------------|---|
| Mercury | 4878 | Small bead | 0.2 cm | sf = 4878 km ÷ 0.2 cm sf = 24,390 km/cm |
| Venus | 12,102 | Peppercorn | 0.46 cm | sf = 12,102 km ÷ 0.46 cm sf = 26,309 km/cm |
| Earth | 12,756 | Peppercorn | 0.46 cm | sf = 12,756 km ÷ 0.46 cm sf = 27,730 km/cm |
| Mars | 6792 | Small bead | 0.2 cm | sf = 6792 km ÷ 0.2 cm sf = 33,960 km/cm |
| Jupiter | 142,980 | Rubber ball | 5.5 cm | sf = 142,980 km ÷ 5.5 cm sf = 25,996 km/cm |
| Saturn | 120,536 | Large bobber | 4.6 cm | sf = 120,536 km ÷ 4.6 cm sf = 26,203 km/cm |
| Uranus | 51,118 | Acrylic bead | 1.7 cm | sf = 51,118 km ÷ 1.7 cm sf = 30,069 km/cm |
| Neptune | 49,528 | Acrylic bead | 1.7 cm | sf = 49,528 km ÷ 1.7 cm sf = 29,134 km/cm |
| Pluto | 2340 | Point of a pin | 0.09 cm | sf = 2340 km ÷ 0.09 cm sf = 26,000 km/cm |
| Average Scale Factor (km/cm) | | | | 249,791 km/cm ÷ 9 = 27,755 km = 1 cm |
| FINAL AVERAGE Scale Factor: 1 cm = 27,755 km | | | | |

Inquiry Master 11.3b

Calculating Scaled Distance (Anticipated Responses)

Scale Factor: 1 cm = 27,755 km (scale factors may vary)

Table 1 Calculating Scaled Distance (answers may vary)

| Planet | Actual Distance from Sun (ADs) (km) | Scaled Distance (SDs) (cm) SDs = ADs ÷ Scale Factor (sf) | Scaled Distance Converted (m) or (km) |
|---------|-------------------------------------|---|---------------------------------------|
| Mercury | 57,900,000 | SDs = 57,900,000 ÷ 27,755 SDs = 2086 | 2086 cm ≈ 21 m |
| Venus | 108,200,000 | SDs = 108,200,000 ÷ 27,755 SDs = 3898 | 3898 cm ≈ 39 m |
| Earth | 149,600,000 | SDs = 149,600,000 ÷ 27,755 SDs = 5390 | 5390 cm ≈ 54 m |
| Mars | 228,000,000 | SDs = 228,000,000 ÷ 27,755 SDs = 8215 | 8215 cm ≈ 82 m |
| Jupiter | 778,400,000 | SDs = 778,400,000 ÷ 27,755 SDs = 28,045 | 28,045 cm ≈ 280 m |
| Saturn | 1,426,700,000 | SDs = 1,426,700,000 ÷ 27,755 SDs = 51,403 | 51,403 cm ≈ 514 m |
| Uranus | 2,866,900,000 | SDs = 2,866,900,000 ÷ 27,755 SDs = 103,293 | 1.0 km ≈ 0.6 miles |
| Neptune | 4,486,100,000 | SDs = 4,486,100,000 ÷ 27,755 SDs = 161,632 | 1.6 km ≈ 1 mile |
| Pluto | 5,890,000,000 | SDs = 5,890,000,000 ÷ 27,755 SDs = 212,214 | 2.1 km ≈ 1.5 miles |

Name: _____

Class: _____ Date: _____

Student Sheet 11.1

Our Solar System Model

Directions Complete Table 1 Model Size and Distance. Then draw a picture of your solar system model and label it. Note any similarities in sizes of or distances between your model planets.

Table 1 Model Size and Distance

| Planet | Object Representing the Planet | Diameter of Object (cm) | Distance of Object From the End of the Paper ("Sun") (cm) |
|---------|--------------------------------|-------------------------|---|
| Mercury | | | |
| Venus | | | |
| Earth | | | |
| Mars | | | |
| Jupiter | | | |
| Saturn | | | |
| Uranus | | | |
| Neptune | | | |
| Pluto | | | |

Drawing of Model Solar System

Name: _____

Class: _____ Date: _____

Student Sheet 11.2

Using a Scale Factor

Directions Use the scale factor (sf) to complete Table 1 below. The first row is completed as an example for you.

| Planet | Actual Diameter (AD) (km) | Scaled Diameter (SD) (cm) SD = AD ÷ Scale Factor (sf) | Actual Distance from Sun (ADs) (km) | Scaled Distance from Sun (SDs) (cm) SDs = ADs ÷ sf |
|---------|---------------------------|--|-------------------------------------|--|
| Mercury | 4878 | SD = 4878 km ÷ 10,000 km/cm SD = 0.49 cm ≈ 0.5 cm | 57,900,000 | SDs = 57,900,000 km ÷ 10,000 km/cm SDs = 5790 cm ≈ 58 m |
| Venus | 12,102 | | 108,200,000 | |
| Earth | 12,756 | | 149,600,000 | |
| Mars | 6792 | | 228,000,000 | |
| Jupiter | 142,980 | | 778,400,000 | |
| Saturn | 120,536 | | 1,426,700,000 | |
| Uranus | 51,118 | | 2,866,900,000 | |
| Neptune | 49,528 | | 4,486,100,000 | |
| Pluto | 2340 | | 5,890,000,000 | |

Scale Factor: 1 cm = 10,000 km

Table 1 Using a Scale Factor

Name: _____

Class: _____ Date: _____

Student Sheet 11.3a

Calculating the Scale Factor

Directions Complete Table 1 by recording the name and diameter of each of your planetary models in the columns labeled “Scaled Object” and “Scaled Diameter.” Then in the column labeled “Scale Factor,” calculate the scale factor used to create this scale model. Show all work. The first row is completed for you as an example.

Table 1 Calculating the Scale Factor

| Planet | Actual Diameter (AD) (km) | Scaled Object | Scaled Diameter (SD) (cm) | Scale Factor (sf) (km/cm) sf = AD ÷ SD |
|--|---------------------------|---------------|---------------------------|--|
| Mercury | 4878 | Small bead | 0.2 cm | sf = 4878 km ÷ 0.2 cm sf = 24,390 km / cm |
| Venus | 12,102 | | | |
| Earth | 12,756 | | | |
| Mars | 6792 | | | |
| Jupiter | 142,980 | | | |
| Saturn | 120,536 | | | |
| Uranus | 51,118 | | | |
| Neptune | 49,528 | | | |
| Pluto | 2340 | | | |
| Average Scale Factor (km/cm) | | | | |
| FINAL AVERAGE Scale Factor: 1 cm = _____ km | | | | |

Name: _____

Class: _____ Date: _____

Student Sheet 11.3b

Calculating Scaled Distance

Directions Record the scale factor (sf) calculated on Student Sheet 11.3a. Complete Table 1 by calculating the scaled distance for each planetary model. Show all work. The first row is completed for you using the scale factor of 1 cm = 27,755 km. Your scale factor may be different.

Scale Factor: 1 cm = _____ km

Table 1 Calculating Scaled Distance

| Planet | Actual Distance from Sun (ADs) (km) | Scaled Distance (SDs) (cm) SDs = ADs ÷ Scale Factor (sf) | Scaled Distance Converted (m) or (km) |
|---------|-------------------------------------|---|---------------------------------------|
| Mercury | 57,900,000 | SDs = 57,900,000 km ÷ 27,755 km/cm SDs = 2086 cm | 2086 cm = 21 m |
| Venus | 108,200,000 | | |
| Earth | 149,600,000 | | |
| Mars | 228,000,000 | | |
| Jupiter | 778,400,000 | | |
| Saturn | 1,426,700,000 | | |
| Uranus | 2,866,900,000 | | |
| Neptune | 4,486,100,000 | | |
| Pluto | 5,890,000,000 | | |