# JOURNEY through the UNIVERSE

## Voyage: A Journey through our Solar System

## Grades 5-8

## Lesson 2: Voyage of Discovery

On a visit to the National Mall in Washington, DC, one can see monuments of a nation—Memorials to Lincoln, Jefferson, and WWII, the Vietnam Veterans Memorial Wall, and Washington Monument. Standing among them is *Voyage*—a one to 10-billion scale model of our Solar System—spanning 2,000 feet from the National Air and Space Museum to the Smithsonian Castle. *Voyage* provides visitors a powerful understanding of what we know about Earth's place in space and celebrates our ability to know it. It reveals the true nature of humanity's existence—six billion souls occupying a tiny, fragile, beautiful world in a vast space.

*Voyage* is an exhibition that speaks to all humanity. Replicas of *Voyage* are therefore available for permanent installation in communities worldwide (http://voyagesolarsystem.org.)

This lesson is one of many grade K-12 lessons developed to bring the *Voyage* experience to classrooms across the nation through the *Journey through the Universe* program. *Journey through the Universe* takes entire communities to the space frontier (http://journeythroughtheuniverse.org.)

*Voyage* and *Journey through the Universe* are programs of the National Center for Earth and Space Science Education (http://ncesse.org). The exhibition on the National Mall was developed by Challenger Center for Space Science Education, the Smithsonian Institution, and NASA.

# Lesson 2: Voyage of Discovery

## Lesson at a Glance

### Lesson Overview

Models are powerful tools of exploration, especially as students investigate the size and distance relationships between the Sun and the planets in the Solar System. Examining the relative sizes of the planets using models at a one to ten billion scale, students realize that the Earth, the biggest thing they have ever touched, is quite small in comparison to the Sun and some of the other planets. Moving outdoors, students then create a one to ten billion scale model of the Solar System. Walking through their model as cosmic giants, students are awed by the tiny worlds in a vast space, and gain a new appreciation for Earth, their home.

### Lesson Duration

Two 45-minute class periods

### Core Education Standards

*National Science Education Standards*

Standard D3: Earth in the solar system

- The earth is the third planet from the sun in a system that includes the moon, the sun, eight other planets and their moons, and smaller objects, such as asteroids and comets. The sun, an average star, is the central and largest body in the solar system.

*AAAS Benchmarks for Science Literacy*

Benchmark 4A3:

- Nine planets* of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The earth is orbited by one moon, many artificial satellites, and debris.

  **Since the time these standards were written, the International Astronomical Union decided that there are only eight major planets in the Solar System. The former ninth planet, Pluto, is now a dwarf planet.*

## Related Education Standards

*AAAS Benchmarks for Science Literacy*

Benchmark 4A2:

- The sun is many thousands of times closer to the earth than any other star. Light from the sun takes a few minutes to reach the earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years. Some distant galaxies are so far away that their light takes several billion years to reach the earth. People on earth, therefore, see them as they were that long ago in the past.

## Essential Questions

- How are models useful for studying the Solar System?
- What are the relative sizes of the planets and the Sun, and the distances between them?

## Concepts

Students will learn the following concepts:

- Models are powerful tools of exploration.
- Physical models are 2- or 3-dimensional representations that share one or more characteristics of the object being studied.
- The Sun is the largest object in the Solar System, and the Earth is a relatively small planet.
- The Sun and the planets are tiny worlds in the vast amount of space contained in the Solar System.

## Objectives

Students will be able to do the following:

- Model the relative sizes of the Sun and planets using familiar materials such as food stuffs.
- Construct a one to 10 billion scale model of the Solar System,
- Describe how the sizes of the Sun and planets in the Solar System compare to the distances between them.

# Science Overview

Earth is home to the human race. From our origins in eastern Africa, modern humans have spread to inhabit all the continents on Earth, even reaching into frigid, inhospitable Antarctica. Humanity has also taken its first steps beyond Earth by sending humans to the Moon, Earth's celestial neighbor, and by sending dozens of robotic spacecraft to study objects across the Solar System.

## Solar System in a Nutshell

The major components of the Solar System are the Sun and the eight planets revolving around it. The Solar System also includes the moons of the planets, asteroids, comets, dwarf planets, and small icy bodies beyond Neptune.

The Solar System is truly the family of the Sun. The planets, asteroids, and comets orbit the Sun, while the moons orbit their parent planets. The Sun's central role derives from its high mass; it has 99.8% of the mass in the Solar System and, therefore, guides the movement of the other objects via gravitational forces. The light emitted by the Sun bathes the solar system with energy that powers weather on the planets.

There are two basic types of planets. Earth-like ("terrestrial") planets—Mercury, Venus, Earth, and Mars—are small, dense, rocky worlds. They have solid surfaces and are located in the inner part of the Solar System. Jupiter-like ("Jovian") planets—Jupiter, Saturn, Uranus and Neptune—are large planets located further out in the Solar System. They have no solid surface on which to stand, and the apparent visible surfaces are just the top layers of clouds in their atmospheres. The Jovian planets are gas giants—large rapidly rotating objects made mostly of hydrogen and helium. To provide a sense of size, eleven Earths could stretch side-by-side across Jupiter's equator, and two Earth's can comfortably fit inside a storm on Jupiter called the Great Red Spot.

Pluto used to be known as the ninth planet in the Solar System, but its basic properties—size, composition, orbit around the Sun—makes it a poor fit into either the terrestrial or Jovian categories of planets. Instead, Pluto appears to be more closely related to the small icy worlds most commonly called Kuiper Belt Objects (KBOs) that astronomers have discovered beyond Neptune's orbit since 1992. When one of these objects (called Eris) was discovered to be larger than Pluto, the International Astronomical Union decided in 2006 that Pluto cannot be considered a real planet any more, and instead belongs to a new class of objects called dwarf planets. Pluto is included in the discussion here as an example of dwarf planets.

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## Exploring the Solar System with Models

In discussing the properties of the Solar System, it is easy to lose sight of the vast distances between the Sun and planets when compared to their small sizes. One way to truly visualize the Solar System is through the use of an accurate model.

There are many objects or phenomena that are difficult to study because they are too complex, or simply too large or too small. Exploring the Earth took centuries because of its immense size compared to that of a human explorer. Uncovering the secrets of a cell, or the nucleus of an atom, was also difficult due to the minute size of these objects. Models offer one means of representing an object or a phenomenon in a simple or manageable way, thereby proving a powerful means of learning about the real object or phenomenon.

For the purposes of this lesson, a model can be defined as either *physical* or *mathematical*, representation that shares one or more characteristics of the object or phenomenon it depicts. Physical models can be 3-dimensional, with surfaces and mass; or 2-dimensional, "flat." They can be larger or smaller than the real object. Examples of these kinds of models include model trains, toy cars, city maps, photographs of a person, and a toy version of an igloo. A physical model is often created to be about the size of a human for ease of study. Mathematical models are quantitative or symbolic representations of a concept, process, or phenomenon. For example, multiplication tables reflect a shortcut to the process of counting. A bar chart may indicate the most popular ice cream flavors.

Constructing a physical model of the Solar System is a good way to bring the vast distances between the Sun and planets down to a level that is more manageable and understandable by humans.

## Scale Models

A physical model is particularly useful if it is a *scale* model. This means that all parts of the model are scaled up or down by the same factor. For example, if there is a wall with dimensions 10 m x 3 m, and there is a 1 m x 1 m window in the middle of the wall, it can be represented in a scale model drawing on paper as a 10 cm x 3 cm wall, with the window now depicted at 1 cm x 1 cm. The ratio of the size of the model to the original size is the same for all parts of the model. This ratio defines the 'scale' of the model. Example ratios for the case of the drawing of the window on the wall include the following:

$$\frac{\text{model window width}}{\text{real window width}} = \frac{\text{model window height}}{\text{real window height}} = \frac{\text{model wall width}}{\text{real wall width}} = \frac{\text{model wall height}}{\text{real wall height}}$$

Any one of these ratios provides the scale of the model; in this case, the scale is 1 to 100 (10 cm vs. 10 m). In a scale model, the quantities that are 'to scale' include distances and sizes, but not areas and volumes. For example, the area of the real window is much larger than 100 times the area of the model window.

The Solar System can be studied with the help of a scale model. If the Sun is represented by a large grapefruit 14 cm (5.5 inches) in diameter, Earth would be a sphere 1.3 mm (0.05 inches) in diameter, located 15 m (49 ft) away. In this case, the scale of the model is one to 10 billion. (The real Solar System is therefore ten billion times larger than the model.) On this scale, Pluto would be almost 600 m (2,000 ft) away, and the nearest star to the Solar System, Proxima Centauri, would be over 4,000 km (2,500 miles) away. A scale model of the Solar System at exactly this scale is located in Washington, D.C. In this model, the planetary range of the Solar System (Sun to Pluto) fits within the National Mall, while the nearest star would be the size of a cherry located on the coast of California (visit www.voyagesolarsystem.org).

### Sizes and Distances in the Solar System

Astronomers do not necessarily create scale models of the Solar System in order to study it, but they do use units of distance, mass, and time that make the numbers characterizing the Solar System more manageable and understandable. To this end, distances are measured in Astronomical Units (AU), which is the average distance between the Earth and the Sun, or 150 million km (93 million miles). That is, Earth's distance from the Sun is 1 AU. This makes it easy to note that Jupiter is over five times as far from the Sun as Earth (Jupiter's average distance from the Sun is 5.2 AU), and Pluto is almost 40 times as far from the Sun as Earth (Pluto's average distance from the Sun is 39 AU). In Table 1, the basic properties of the planets are given in terms of AU, Earth masses, and Earth days or years.

Table 1: Properties of the Planets in the Solar System
Pluto is included as an example of dwarf planets

| | Mercury | Venus | Earth | Mars | Jupiter | Saturn | Uranus | Neptune | Pluto (dwarf planet) |
|---|---|---|---|---|---|---|---|---|---|
| Mean distance from Sun (Astronomical Units) | 0.387 | 0.723 | 1.000 | 1.524 | 5.204 | 9.582 | 19.201 | 30.047 | 39.482 |
| Mass (Earth masses) | 0.055 | 0.815 | 1.000 | 0.107 | 318 | 95.2 | 14.5 | 17.1 | 0.0021 |
| Orbital period; or length of one of planet's years (Earth days or years) | 88 days | 225 days | 365.3 days | 687 days | 11.9 years | 29.5 years | 84.0 years | 164.8 years | 247.7 years |
| Diameter (kilometers) | 4,880 | 12,100 | 12,800 | 6,790 | 143,000 | 121,000 | 51,100 | 49,500 | 2,390 |
| Atmosphere (main components) | Virtually a vacuum | Carbon Dioxide | Nitrogen, Oxygen | Carbon Dioxide | Hydrogen, Helium | Hydrogen, Helium | Hydrogen, Helium, Methane | Hydrogen, Helium, Methane | Methane, Nitrogen |
| Moons | 0 | 0 | 1 | 2 | 63 | 61 | 27 | 13 | 3 |
| Rotation period | 59 Earth days | 244 Earth days retrograde* | 23 hours 56 min | 24 hours 37 min | 9 hours 56 min | 10 hours 39 min | 17 hours 14 min retrograde* | 16 hours 7 min | 6.4 Earth days retrograde* |

*Numbers in the table are valid as of June 2010.*

*One can imagine looking down on the Solar System from high above the Sun's north pole. From this vantage point all the planets revolve counterclockwise around the Sun. Also from this vantage point, most of the planets are seen to rotate on their axes counterclockwise. However, Venus, Uranus, and Pluto are seen to rotate clockwise and are said to be rotating 'retrograde'. On the surface of a planet with retrograde rotation, the Sun would appear to rise from the west and set in the east.

# Conducting the Lesson

## Warm-Up & Pre-Assessment

### Teacher Materials

- A map of your home state
- 2- and 3-dimensional models of the Earth, the planets, and the Solar System to place around the room (e.g., posters, pictures, a globe)

### Preparation & Procedures

1. Lead a discussion of the Earth, the Solar System, and why models are useful in studying them. You can begin the discussion by asking, "If you wanted to explore an unfamiliar region of the country, what would you need?" As students begin to offer suggestions, lead them to the concept of a map. Show students a map of your home state and ask them to define a 'map'. Use leading questions and statements: "What kinds of information are contained on a map?" and "How does the size of the map compare to the real size of the state?" After students conclude the map is smaller than the state, ask them if a six story high map—which is still very much smaller than the state—would be a useful map. The students should conclude that a map is a 2-dimensional representation of a part of the world, that often contains a great deal of information, and whose size makes it comfortable for us to hold and use. A map is clearly a powerful tool of exploration.

2. Ask the students if they know that a map is an example of a more general tool used to explore. Lead them to the concept that a map is a type of model. Use leading questions and statements: "How can you learn about the different parts of an airplane?" *(Desired answer: a diagram of an airplane is a model, as is an airplane that can be bought in the toy store*) or "How can you learn about things that are a great deal larger or smaller than you?" *(Desired answer: a model of the Earth—a globe—or a model of a cell, allow us to explore this things comfortably.)* Have them define a 'model' in the context of a physical model. A physical model is a 2- or 3-dimensional representation of an object that shares one or more characteristics of the object, e.g. shape or color. While the object is often much larger or smaller than we are, we usually make a model about our size so that the object it represents can be easily studied. A map is a good example of a model. Even a photograph or drawing is an example of a model.

3. Discuss with the students what a model requires to be called a 'scale model'. Use leading questions and statements: "If your model airplane says '1 to 100 scale' on the box, what does that mean?" *(Desired answer: the model plane is 100 times smaller than the real thing. Each part on the model plane—wings, wheels, windows, etc.—is 100 times smaller than the real thing)* A scale model is associated with a 'scale' that defines how much smaller or larger the model is compared to the real object it represents. All the pieces of a scale model are smaller or larger than the real pieces by the same scale. So in a one to 10 billion scale model of the Solar System, all the components of the model—Sun, planets, moons, asteroids, and comets—are ten billion times smaller than the real components. The distances between these objects in the scale model Solar System are also ten billion times smaller than the real distances.

4. Have each student locate a model of the Earth and the other planets around the room, keeping in mind that models can be 2- or 3-dimensional. Do not move on until you have assessed, from students' verbal responses, that everyone knows the definition of a model. A globe, a map, or pictures are examples of models.

## Activity 1: Exploring Planet Sizes

Students will make predictions about the sizes of the planets in the Solar System, including the Earth, on a one to ten billion scale using models. Students will compare the size of the Earth to the other planets, and realize that the Earth is a rather small planet.

### Teacher Materials

- A round yellow balloon

### Student Materials (per student)

- Student Worksheet 1
- Ruler with millimeter divisions
- Calculator

### Preparation & Procedures

1. Ask students, "What is the biggest thing you have ever touched?" Some students might say a large building, or the ocean. Lead them to the answer with statements like "Everyone has touched it. You are sitting on it right now. It is underneath us." Lead them to the conclusion that the Earth, their home in the Solar System, is the biggest thing they have ever touched.

2. Blow up a yellow balloon to a diameter of 14 cm to represent the Sun. Show students the model of the Sun. Based on the size of the model Sun, have students answer the questions in Student Worksheet 1; do not pass out Student Worksheet 2 until Activity 2 since it will give away the answers.

3. After the students have completed Student Worksheet 1, give students the following hints, one at a time. After each hint, give them the opportunity to correct their predictions. Allow them to use the ruler and calculator as needed. *(Refer to the Teacher Answer Key for the correct answers).*
   - (Question 1) It would take 109 Earths to fit across the Sun. (*Hint:* What is 1/109 of 14 cm?)
   - (Question 3) 11 Earths would fit across the largest planet.
   - (Question 4) 107 Suns would fit between the Earth and Sun.

   Once students complete Student Worksheet 1, collect it for assessment.

### Reflection & Discussion

Begin with a review of the answers and how the hints provided a pathway to those answers. Ask students, "What have you learned in this activity and did anything surprise you?" Students should reflect on the small size of Earth compared to Jupiter and the Sun. Students should also be surprised by the small size of Earth relative to the distance between the Earth and Sun. Referring to questions 5 and 6 on Student Worksheet 1, explore how the models can be useful, and how the models can be improved (see *Teacher Answer Key*). Lead students to the conclusion that one improvement would be creating models of all the planets and placing them at the correct distances from the Sun—creating a scale model of the Solar System at the one to 10 billion scale.

### Transfer of Knowledge

Ask students to come up with one question that would be very difficult to answer without the use of models. The question can be related to the Earth, the Solar System, or an everyday object. For example: "Which is bigger, Africa or Australia?" "Which is bigger, Mars or Neptune?" A more complicated question might be, "If we were to dig a hole through the Earth, where would we come out?" *(Hint: It's not China.)* Students could use a globe to find the answer, but without a model, they would actually have to dig a hole through the Earth! Have students write down their questions and hand them in for assessment.

## Assessment Criteria for Activity 1

5 Points
- All questions from Student Worksheet 1 are answered.
- All answers have been reviewed by the student, changed if needed, and are now correct.
- *Transfer of Knowledge* question that student developed is answered easily through modeling.

4 Points
- All questions from Student Worksheet 1 are answered.
- Most answers have been reviewed by the student, changed if needed, and are now correct.
- *Transfer of Knowledge* question that student developed is answered easily through modeling.

3 Points
- All questions from Student Worksheet 1 are answered.
- Most answers have been reviewed by the student, changed if needed, and are now correct.
- *Transfer of Knowledge* question that student developed does not really need a model to easily answer.

2 Points
- Most questions from Student Worksheet 1 are answered.
- Some answers have been reviewed by the student, changed if needed, and are now correct.
- *Transfer of Knowledge* question that student developed does not really need a model to easily answer.

1 Point
- Some questions from Student Worksheet 1 are answered.
- Some answers have been reviewed by the student, changed if needed, and are now correct.
- *Transfer of Knowledge* question that student developed does not really need a model to easily answer.

0 Points
- No work was completed.

## Extensions

Have students create or use a model to solve the question they developed in the *Transfer of Knowledge* section.

## Placing the Activity Within the Lesson

Based on the class conversation during the *Warm-Up & Pre-Assessment*, students should realize that they can use models as tools of exploration. Students will use the knowledge they gained from Activity 1 to construct a scale model of the Solar System in Activity 2.

## Notes on Activity 1:

## Activity 2: Making a Scale Model of Our Solar System

Students will create a scale model of the Solar System that is one 10-billionth actual size to investigate the relative sizes of the Sun and planets, and the distances between them.

### Teacher Materials

- Meter stick
- Masking tape
- A copy of *Solar System Questions and Fun Facts* found in the back of the lesson
- A copy of the *Teacher Answer Key* found in the back of the lesson

### Student Materials (per student)

- Student Worksheet 2
- A few of each of the following:
  - Poppy seeds
  - Mustard seeds
  - Spherically shaped cereal (e.g., Kix)
  - Soy beans
  - Small gum balls
  - Black pepper grains (ground)
- Transparent tape
- Scissors
- Masking tape
- 10 poster boards
- A round yellow balloon
- 10 items to fasten the Sun and the planets to the ground (e.g., sticks, tomato stakes, etc.; see the Teaching Tip on the next page)
- Ruler with millimeter divisions
- Calculator

### Preparation & Procedures

1. Find an area outside to walk 600 meters (0.4 miles) in a straight line if you want to pace out the entire Solar System. You only need half this distance if you pace from the Sun to Uranus, which is half-way to Pluto. Each team will create and pace out their own model Solar System. The number of teams depends on

> **Teaching Tip**
>
> While the food suggestions are only a guide, it is very useful to model the planets using real-world objects. It is simply easier to remember that something is about the size of a poppy seed than it is to remember actual dimensions or approximations.

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the number of model Solar Systems that can be paced out side-by-side, simultaneously. The number of teams per class will therefore depend on the width of the path available.

2. Place students in teams.

3. Collect food items for the Model Planet Cards. See the *Teacher Answer Key* for which planets are to be represented by the different food items.

4. Hand out Student Worksheet 2 and make the student materials available. Be sure to allow students the opportunity to choose which foods will represent each planet. Have students follow the directions on Student Worksheet 2 to create their model planets.

5. Before taking the class outside, introduce the "pace" as the "ruler" for this model Solar System. Define a pace as two steps, one with each foot. Put a few parallel strips of masking tape on the floor, one meter apart, and ask students to walk back and forth, getting used to the size of a meter pace. For a class of taller students, you might want to define a pace as one step.

6. Take your class outside to walk the length of the model Solar System. Have each team take their completed set of model planets and Sun outside, and each student should take Student Worksheet 2, a pencil, and a book to support the Student Worksheet. Also, take along the *Teacher Answer Key*, as well as the *Solar System Questions and Fun Facts* page to refer to while you are walking the model, which will allow you to take the class on a 'tour' of the Solar System.

7. Have each team place their model Sun by pushing the attached stake into the ground. All of the Suns should be in a line to ensure the same starting point. Share with the class the *Solar System Questions and Fun Facts* that pertain to the Sun.

**Teaching Tip**

The stakes attached to the model planets can be a variety of household items. For example, you may use tomato stakes, dowels, chop-sticks, shish kabob skewers, etc. The idea is that the planets will be visible from any point along the path in your model. If you are creating your scale model on pavement, or if the ground is very hard, you can create tent cards out of poster board or put the stakes inside the center of construction cones. Be creative!

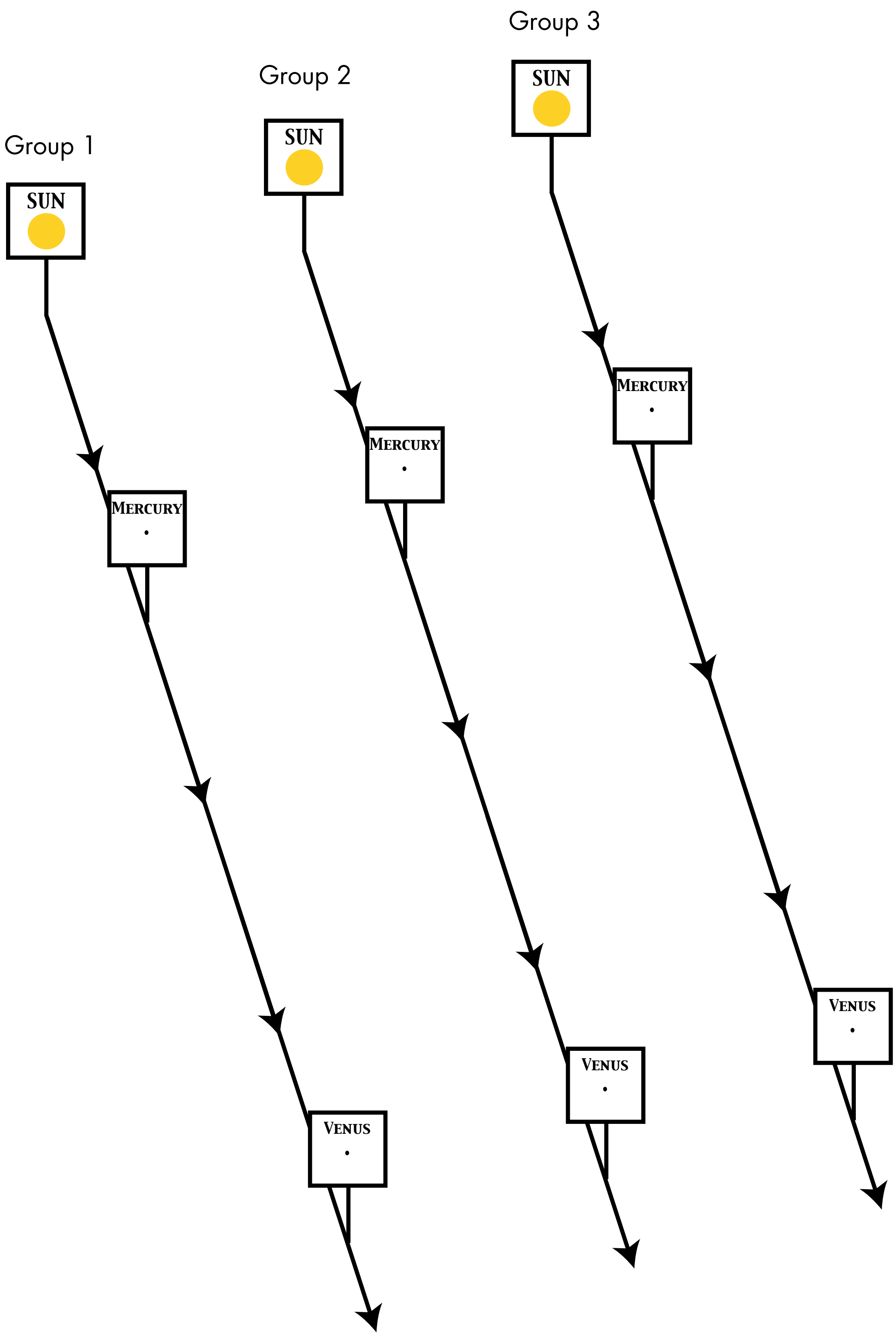


*Figure 1. Pacing out the Solar System. Each group places the Sun on the ground, paces the distance to Mercury, places the Model Planet Card on the ground, paces the distance to Venus, etc.*

8. Have the class guess the number of paces to Mercury. Give them the answer from the *Teacher Answer Key*, and explore whether they are surprised. Have each team pace out the distance to where the model Mercury should be and push the attached stake into the ground. Have them record the number of paces in the second column of the Model Distance Chart on Student Worksheet 2. Then have them calculate the total number of paces from the model Sun and record it in the third column. Note that the values for the second and third columns are only the same for Mercury (see *Teacher Answer Key*.) Share with the class the *Solar System Questions and Fun Facts* that pertain to Mercury.

TEACHING TIP

If you do not have space (or time) to model all of the planets, you might continue with the model until you reach Uranus. At this point, you can stop and tell the students, "Now we are only half way to Pluto!" and read the *Solar System Questions and Fun Facts* for the rest of the Solar System from Uranus.

9. Repeat step 8 for the remaining planets. The students will likely be shocked at the number of paces to each planet once they move beyond Mars. Note that it is okay if the location of a particular planet is different for different teams. The students providing the 'official' paces for each team may not have identical one meter paces. These variations will be discussed in the *Reflection & Discussion* section.

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### Reflection & Discussion

1. Ask students what they found to be the most impressive aspect of the model Solar System. A great number of comments might result, including: the distances between the planets are large compared to their small sizes; even the Sun is small compared to the distances between worlds; the inner planets are all located close to the Sun; and the distances between the outer planets are vast.

2. Many model Solar Systems that students have seen show the planets' sizes on one scale, and the distances between them on another, making the planets appear much closer together than they really are. Help students realize the difficulty in representing both the sizes and the distances accurately on the same scale. Use a diagram of the Solar System from your textbook and compare it to the model the students just made. Challenge students to explain the reason for any differences. *(Desired answer: if the distances between the Sun and planets were to be represented accurately in a book, and the Sun-Pluto distance portrayed on a single page, then the planets would be too small to see)* Lead them to the concept that the model they created today showed the size of the planets and their distance on the same scale.

3. Oftentimes the same planet for different teams will not be at the exact same distance from the Sun. Ask students why they think these differences may occur. *(Desired answer: this is due to variations in pace length from team to team)* Note that the differences in a planet's location from team to team become greater as the distance from the Sun increases. The variations between paces are compounded as the number of paces from the Sun increases.

4. Ask the students if the planets are actually very large or very small. Both answers are correct. In comparison to the Solar System as a whole they are very small objects. However, from a human's point of view the planets are very large and majestic objects.

#### Curriculum Connections

*Mathematics:* Have students create a model of themselves on a scale of one to ten. Have them measure their own (or a partner's) face length, arm length, leg length, etc., and calculate the size of each part on the model.

### Transfer of Knowledge

Back in the classroom, have the students separately calculate the actual distance from the Sun to each planet and record it in the fourth column of the table on Student Worksheet 2. In order to complete the table they must demonstrate an understanding that the actual distances are 10 billion times greater than the model distances found in the third column.

#### Lesson Adaptations

*Talented and Gifted:* Add a fifth column to the table in Student Worksheet 2 and have students calculate the distance from the Sun to each planet in terms of Sun-Earth distance. Have students find out what this distance is called. *(Desired Answer: Astronomical Unit)* These distances are listed in Table 1 in the *Science Overview*.

## Assessment Criteria for Activity 2

5 Points

- All of the food items chosen to represent the planets have been taped to the correct model planets.
- All of the distances between model planets are correct on Student Worksheet 2.
- All of the model planets' distances from the model Sun are correct on Student Worksheet 2.
- All of the actual planets' distances from the real Sun are correct on Student Worksheet 2.

4 Points

- All of the food items chosen to represent the planets have been taped to the correct model planets.
- All of the distances between model planets are correct on Student Worksheet 2.
- Almost all of the model planets' distances from the model Sun are correct on Student Worksheet 2.
- Almost all of the actual planets' distances from the real Sun are correct on Student Worksheet 2.

3 Points

- All of the food items chosen to represent the planets have been taped to the correct model planets.
- All of the distances between model planets are correct on Student Worksheet 2.
- Most of the model planets' distances from the model Sun are correct on Student Worksheet 2.
- Most of the actual planets' distances from the real Sun are correct on Student Worksheet 2.

2 Points

- Most of the food items chosen to represent the planets have been taped to the correct model planets.
- Most of the distances between model planets are correct on Student Worksheet 2.
- Some of the model planets' distances from the model Sun are correct on Student Worksheet 2.
- Some of the actual planets' distances from the real Sun are correct on Student Worksheet 2.

1 Point

- Some of the food items chosen to represent the planets have been taped to the correct model planets.
- Some of the distances between model planets are correct on Student Worksheet 2.
- A few of the model planets' distances from the model Sun are correct on Student Worksheet 2.
- A few of the actual planets' distances from the real Sun are correct on Student Worksheet 2.

0 Points

- No work was completed.

## Extensions

- The Moon orbits the Earth at a distance of 384,400 km. Have students calculate how far this distance would be on the scale model. On this scale, the entire orbit of the Moon could fit into the palm of their hand. You can repeat this for the moons of other planets, as well. (Distances between planets and their moons can be found on The Nine Planets web site: http://www.nineplanets.org.)

- Have students research the time it takes for the four inner planets to orbit the Sun, and act out the motions of these planets in the model Solar System. For every time Mars orbits once, Earth orbits almost twice, Venus three times, and Mercury nearly eight times. (See Table 1 in the *Science Overview*.)

## Placing the Activity Within the Lesson

Refer back to the *Warm-Up & Pre-Assessment* and Activity 1 and discuss how models are powerful tools of exploration for learning about the Earth and beyond.

## Notes on Activity 2:

## Lesson Wrap-Up

### Transfer of Knowledge for the Lesson

In order for students to apply what they have learned, have them use the scale model of the Solar System they just created to answer the questions in Student Worksheet 3. (Answers are located in the *Teacher Answer Key*.)

### Assessment Criteria for the Lesson

5 Points
- Student answered all six questions correctly.
- Student showed work for all questions that displayed a deep and thorough understanding.

4 Points
- Student answered five questions correctly.
- Student showed work for all questions that displayed a thorough understanding.

3 Points
- Student answered three questions correctly.
- Student showed work for all questions that displayed an understanding of the concepts.

2 Points
- Student answered two questions correctly.
- Student showed work for all questions, even if reasoning was sometimes faulty.

1 Point
- Student answered one question correctly.
- Student showed work for all questions, even if reasoning was faulty.

0 Points
- No work was completed.

## Lesson Closure

During this lesson, students started by exploring the concept of models during the *Warm-Up & Pre-Assessment*. During Activity 1, students explored the relative sizes of the planets. They also were taught how large objects could be explored through the use of models. In Activity 2, students created a scale model of the Solar System. Ask students what knowledge they were able to gain from the model that would otherwise be impossible for them. How big is this massive planet we call Earth, the biggest thing we have ever touched, in comparison to the rest of the Solar System?

## Extensions for the Lesson

- Encourage students to research and create 3-dimensional scale models of other objects in the Solar System, Galaxy, or Universe.
- To give your students an added challenge, have them complete the extension questions on Student Worksheet 4.

Notes:

# Resources

## Internet Resources & References

*Student-Friendly Web Sites:*

Astro for Kids
www.astronomy.com/asy/default.aspx?c=ss&id=127

Kids Astronomy
www.kidsastronomy.com/solar_system.htm

NASA for Students
www.nasa.gov/audience/forstudents/5-8/

Star Child
starchild.gsfc.nasa.gov

*Teacher-Oriented Web Sites:*

American Association for the Advancement of Science, Project 2061
Benchmarks for Science Literacy
www.project2061.org/tools/benchol/bolframe.htm

Exploring Planets in the Classroom
www.spacegrant.hawaii.edu/class_acts/

NASA Quest
quest.arc.nasa.gov/sso/teachers/

National Science Education Standards
www.nap.edu/html/nses/

The Nine Planets
www.nineplanets.org

Pro-Teacher
www.proteacher.com/110066.shtml

StarDate Online
stardate.org/resources/ssguide/

Voyage: A Journey through Our Solar System
www.voyagesolarsystem.org

Journey through the Universe
www.journeythroughtheuniverse.org

Discussion about Pluto's reclassification as a dwarf planet
www.voyagesolarsystem.org/pluto/pluto_default.html

## Solar System Questions and Fun Facts

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The **Sun** is a star. Why does it look so big and bright compared to the other stars?
*Because it is much closer than the other stars, not because it is bigger—it is only an average sized star.*

Did the position of **Mercury** surprise you?

**Mercury** orbits the Sun faster than any other planet (once every 88 days).

For many years, people called **Venus** Earth's "sister planet." Why do you think they did this?
*Because Venus is about the same size as Earth. We have known this since 1761.*

**Venus** is the second brightest object in the night sky; only the Moon is brighter.

How long does it take the **Earth** to go around the Sun once?
*One year.*

How many **Earths** do you think would fit inside the Sun?
*One million.*

If you wanted to gift-wrap the **Moon**, you would need a piece of wrapping paper the size of Africa.

The total area of **Mars's** surface is about the same as all the dry land on Earth.

Why does **Mars** appear red?
*Mars' surface contains iron oxide, also known as rust, which gives it its red color.*

Between which planets is the **asteroid** belt?
*Mars and Jupiter.*

If you wanted to tie a ribbon around Ceres, the largest **asteroid**, you would need a ribbon long enough to go from northern Maine to southern Florida.

**Jupiter** is the first of the Jovian planets. How do their compositions differ from those of the inner, or terrestrial planets?
*The terrestrial planets have a solid, rocky surface. The Jovian planets do not have a solid surface that we can see; they are gas giants.*

**Jupiter** has a giant storm in its atmosphere, called the Great Red Spot, which could swallow almost three Earths.

More than 1,000 Earths could fit inside **Jupiter**, but over 900 Jupiters could fit inside the Sun.

**Saturn** is the least dense of all of the planets. It is the only planet with a density less than that of water—that means that if there were a bathtub big enough to hold Saturn, it would float.

Traveling from the Sun, once you get to **Uranus**, you are only half-way to Pluto.

**Uranus** is the only planet that rotates on its side, instead of upright.

Like Earth, **Neptune** has four seasons each year. However, one Neptunian year equals 165 Earth years. How long does each season last?
*Each season lasts approximately 41 Earth years.*

It takes **Pluto** 248 Earth years to go around the Sun once. Pluto has not had enough time to go around the Sun once since the Declaration of Independence was signed in 1776.

**Pluto's** orbit is the most elliptical among the worlds included in the *Voyage* model—sometimes it actually is closer to the Sun than Neptune.

**Pluto's** orbit is by no means at the edge of the Solar System. The Oort Cloud, home of the comets, extends almost half-way to the nearest star.

## General Solar System Questions

How do the distances to the Sun compare for the inner (Mercury through Mars) versus the outer (Jupiter through Uranus) planets and Pluto?

*All the inner planets are relatively close to the Sun while the outer planets are far from the Sun and from one another.*

How do the sizes of the inner and outer planets compare?

*Inner planets are generally much smaller than the outer planets. (The inner planets are also all rocky and are called terrestrial planets. The outer planets are gaseous giants, and are called Jovian planets. Pluto is the exception to this rule; in fact, it belongs to a group of objects called dwarf planets.)*

Which of the planets have rings?

*All of the Jovian planets (outer gas giants) have rings (Jupiter, Saturn, Uranus, and Neptune), although Saturn has by far the most extensive system.*

How fast do you think a spacecraft would travel on this model?

*In this model, a spacecraft might move an average of 3 cm (1 inch) every 5 hours.*

If we placed the model Sun in Washington, D.C., how far away would you have to put the model of the next star, Proxima Centauri?

*Over 4,000 km (2,500 miles) away, on the coast of California. Proxima Centauri on this scale would be the size of a cherry. Depending on where you are setting up your model Solar System, you might be able to identify something familiar to the students that is 4,000 km away.*

## Teacher Answer Key

*Student Worksheet 1*

1. D (The Sun is 14 cm in diameter; 14 cm / 109 = 1.3 mm Earth, which is the size of D)
2. Jupiter
3. B (Earth measures 1.3 mm in diameter; 1.3 mm x 11 = 14.3 mm, which is the size of B)
4. Earth is about 15 m (49 ft) away from the model Sun. (The Sun is 14 cm in diameter; 14 cm x 107 = 1,500 cm, or 15 m (49 ft)).
5. The models are useful because they show the planets' relative sizes, on a human scale. We can see, for example, that Jupiter is much larger than the Earth, and that the Sun is much larger than Jupiter.
6. They could be improved by showing, for example, the planets' colors, rings, and prominent features. You could also show the distances between the planets, which means you'd be building a scale model of the Solar System!

*Student Worksheet 2*

Suggested foods for Model Planet Cards*

| | |
|---|---|
| Mercury | Poppy seed |
| Venus | Mustard seed |
| Earth | Mustard seed |
| Mars | Poppy seed |
| Jupiter | Gumball |
| Saturn | Spherical cereal (e.g. Kix) |
| Uranus | Soybean |
| Neptune | Soybean |
| Pluto | Small fleck of ground pepper |

* These foods are only suggestions. You can use any spherical foods that approximate the size of the model planets.

In the Model Distances Chart below, the fourth column is calculated recognizing that in a one to 10 billion scale model Solar System the real distances must be 10 billion times larger than the model distances. Since each entry in the third column is a model distance in paces (meters) the actual distance in meters is obtained by multiplying by 10 billion.

## Model Distances Chart

| | Paces (or meters) between models | Total paces (in meters) from model Sun to each model planet | Distance from the Sun to each planet in meters |
|---|---|---|---|
| Sun to Mercury | 6 meters | 6 meters | 60,000,000,000 |
| Mercury to Venus | 5 meters | 11 meters | 110,000,000,000 |
| Venus to Earth | 4 meters | 15 meters | 150,000,000,000 |
| Earth to Mars | 8 meters | 23 meters | 230,000,000,000 |
| Mars to Jupiter | 55 meters | 78 meters | 780,000,000,000 |
| Jupiter to Saturn | 65 meters | 143 meters | 1,430,000,000,000 |
| Saturn to Uranus | 144 meters | 287 meters | 2,870,000,000,000 |
| Uranus to Neptune | 163 meters | 450 meters | 4,500,000,000,000 |
| Neptune to Pluto | 142 meters | 592 meters | 5,920,000,000,000 |

*Student Worksheet 3*

1. Model Betelgeuse diameter = Model Sun diameter x 1,000

   = 14 cm x 1,000

   = 14,000 cm

   = 140 m

   The model Betelgeuse would be approximately 140 meters in diameter. If you put its center where the model Sun's center is, it would swallow all of the planets that have an orbital radius up to 70 meters. Looking at the chart above, this would include all of the planets up to and including Mars. You can stake a ball of string at the Sun and unwind it until it stretches almost to Jupiter. With the string taut, walk around the Sun at almost Jupiter's distance to outline Betelgeuse. Have students stand around this large circle to see how big Betelgeuse is relative to the Sun.

2. a) Using the ruler, the model Mercury is found to be approximately 0.5 mm in diameter. The model Earth is approximately 1.3 mm in diameter. The ratio of the model diameters is 1.3/0.5 = 2.6. The model Earth is therefore about two and a half times bigger than the model Mercury. While students should be able to describe this procedure, answers may vary given the difficulty in measuring the size of the model Earth and Mercury.

   b) The model Mercury is approximately 0.5 mm in diameter. Multiplied by 10 billion, this means that the real Mercury is about 0.5 x 10,000,000,000 = 5,000,000,000 mm in diameter, corresponding to 5,000 km. Answers within a factor of two are acceptable due to the difficulty in measuring the model Mercury's diameter.

   c) The model Earth is approximately 1.3 mm in diameter. Multiplied by 10 billion, this means that the real Earth is about 13,000 km in diameter. Answers within a factor of two are acceptable due to the difficulty in measuring the model Earth's diameter.

   .

   d) The ratio of the real Earth's diameter to the real Mercury's diameter is approximately 13,000 km / 5,000 km = 2.6. The real Earth is therefore about two and a half times bigger than the real Mercury. This ratio is the same for the actual and scale model planet diameters (see part a above). This shows that you can learn a great deal about the Solar System by using a model.

e) Students can do this a couple of ways.
They can add the model distance from Mercury to Venus and that from Venus to Earth to get 9 meters. If we multiply this by 10 billion, the actual distance from Mercury to Earth is about 90 million kilometers. (More accurately, 92 million kilometers.)

Alternatively, they can use data in the fourth column and subtract the following:

(total distance between the Sun and Earth) – (total distance between Sun and Mercury)

= 150 billion meters – 60 billion meters = 90 billion meters, or 90 million kilometers.

*Student Worksheet 4*

1. Calculation: $\frac{300{,}000{,}000 \text{ m/s}}{10{,}000{,}000{,}000} = 0.03 \text{ m/s (3 cm/s)}$

Since the sizes and distances in the Solar System are represented on a one to 10 billion scale, the speed of light should be represented on the same scale, thus dividing it by 10 billion. Model light would travel only 3 cm/s within the model Solar System, about the speed of a fast ant. It seems pretty slow considering light is the fastest thing in the Universe.

2. From the table on Student Worksheet 2, the distance from the model Jupiter to the model Earth is 78 m – 15 m = 63 m. If we divide by the model speed of light we can get the travel time:

$$\frac{63 \text{ m}}{0.03 \text{ m/s}} = 2{,}100 \text{ seconds (or 35 minutes)}$$

3. The same amount of time it takes within the model, 2,100 seconds (or 35 minutes).

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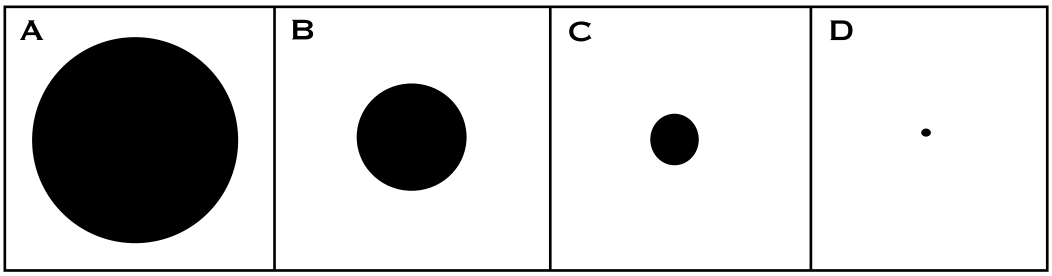
# Student Worksheet 1: Voyage of Discovery

Name ______________________________________________ Date ___________

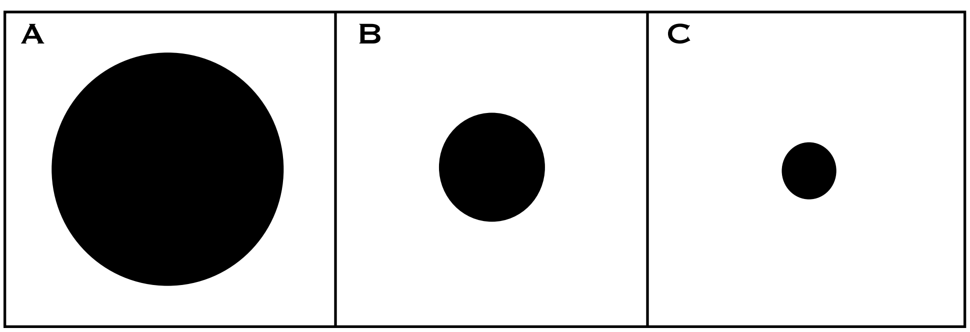
1. If a balloon with a diameter of 14 cm is a model of the Sun, which circle below do you think represents the model Earth? ____________




2. What planet is the biggest? Circle one.

   Earth   Jupiter   Mars   Mercury   Neptune   Pluto   Saturn   Uranus   Venus

3. If a balloon with a diameter of 14 cm is a model of the Sun, which circle below do you think represents the biggest planet? _________

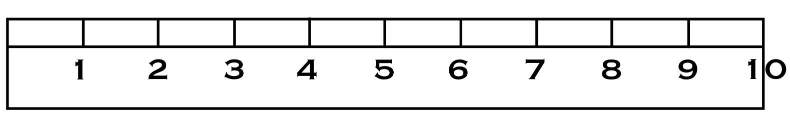



4. Look at your answer for number 1. How far do you think the model Earth should be from the model Sun? ___________

5. How are these models of the planets useful?

6. How could these models be improved?

IMPORTANT NOTE: Your printer may not have produced the planets on these worksheets at their correct size. To check and correct, adjust the enlargement/reduction on your printer to ensure that this ruler measures exactly 10 cm long.




JOURNEY through the UNIVERSE

# Student Worksheet 2: Voyage of Discovery

Name ____________________________________________ Date ___________

1. Match the sizes of the items that your teacher provides to the size of the planets on the cards below. Tape the appropriate size item on top of each of the planets using transparent tape. Cut out the cards below and tape each of them to a separate piece of poster board.
2. Blow up a yellow balloon to approximately 14 cm diameter to represent the Sun. Tape the balloon to another piece of poster board.
3. As directed by your teacher, use masking tape to attach a stick or stake to each piece of poster board, or fold your poster board in half to create tent cards.
4. Use a thick marker and write the name of the planet (or Sun) on the appropriate piece of poster board. Use big letters so that the name of the planet or Sun can be seen from a distance. When finished, you will have 10 poster boards containing your model planets and Sun.

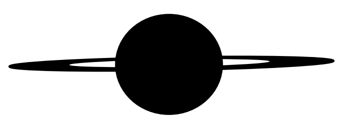
## Mercury

## Venus

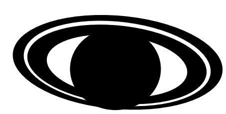
## Earth

## Mars

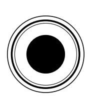
## Jupiter



## Saturn



## Uranus



## Neptune

## Pluto

**Walking the Model Solar System**

Now you and your team are ready to create your own one to ten billion scale model of the Solar System outdoors! You will need to take with you this worksheet, a pencil, and a book or something solid to support the worksheet while you write. Make sure your team takes their model planets and Sun!

1. Place your model Sun as indicated by your teacher.
2. Your teacher will tell you the paces (or meters) between the model Sun and the model Mercury. Write this number in the second column. Pace it out with your team and place your model of Mercury at the correct location. Calculate the total distance you are from the model Sun and write it down in the third column.
3. Repeat step 2 for each planet.

| Model Distances Chart | | | |
|---|---|---|---|
| | Paces (or meters) between models | Total paces (in meters) from model Sun to each model planet | Distance from the Sun to each planet in meters |
| Sun to Mercury | | | |
| Mercury to Venus | | | |
| Venus to Earth | | | |
| Earth to Mars | | | |
| Mars to Jupiter | | | |
| Jupiter to Saturn | | | |
| Saturn to Uranus | | | |
| Uranus to Neptune | | | |
| Neptune to Pluto | | | |

NOTE: Unlike the model Solar System you are creating, the planets never actually all line up on one side of the Sun. They orbit the Sun on different paths at different speeds. The planets even orbit in different planes.

4. Back in the classroom, complete the chart above by filling in the fourth column. (*Hint:* You have built a *one to ten billion scale model* of the Solar System.)

Name ______________________________ Date __________

Be sure to show your calculations along with your answers.

1. Betelgeuse is a star in the constellation Orion. It is 1,000 times as wide as our star, the Sun. Calculate the diameter of Betelgeuse on this scale.

2. a) What is the approximate ratio of the model Earth's diameter to the model Mercury's diameter?

   b) Calculate the actual diameter of Mercury in kilometers. Hint: You will need a ruler, and the scale of the model.

   c) Calculate the actual diameter of Earth in kilometers. Use the same process you used above, in part b.

   d) What is the approximate ratio of the real Earth's diameter to the real Mercury's diameter?

   How does this compare to the ratio of their model diameters you calculated in part a above?

   Why then are models important tools for exploration?

   e) Calculate the actual distance between Earth and Mercury.

## Student Worksheet 4: Voyage of Discovery

Name ______________________________ Date ____________

1. Radio messages travel at the speed of light, 300,000,000 meters per second. Calculate how fast model light would travel within a one to 10 billion scale model of the Solar System.

2. How long would a radio message take to travel from a spacecraft near Jupiter to Earth in our model Solar System?

3. How long would a radio message take to travel from a spacecraft near Jupiter to Earth in the real Solar System? *(Hint: You can do this without a calculator!)*

JOURNEY through the UNIVERSE