Montage of planets. Not to Scale.

Image credit: NASA/JPL

In this Exploration, find out

- How the sizes of the planets compare to each other?
- How far apart are the planets?
- What is a scale model?
- What is the solar system mainly composed of?

Scale Model Solar System

Teacher's Guide

In this exercise (based on the Colorado Model Solar System), students will create their own scale model solar systems from common materials for the purpose of exploring concepts of size and distance in the solar system.

Updated to include the 2006 decision by the International Astronomical Union to designate eight planets and three initial dwarf planets in the solar system; this activity can also serve as an introduction to the classification of planets and dwarf planets.

Grade Level: 6-8

Time Frame: The activity is broken into 2 sections; each will take approximately 45 minutes to 1 hour to complete, including short introductions and follow-ups. If you choose to include dwarf planets, plan on an additional class period. Allow about 20 minutes for students to make their own calculations converting to both the scaled sizes and distances between the planets, or give such assignments as homework before the activity. If the students will complete the size and distance tables in class and you are concerned about time, consider providing a partially completed table for your students.

Curriculum Standards: The Scale Model Solar System is matched to:

- National Science and Math Education Content Standards for grades 5-8.
- National Math Standards 5-8, and 9-12 (Number Systems)

Purpose: To aid students in understanding the scale of the solar system, in both the sizes of objects in the solar system, and the vast distances between the Sun and planets. Understanding the scale of the solar system is a crucial component in understanding the nature of astronomical objects and the universe in which we live.

Materials for Part 1:

- Index cards (9 per group of students)
- Markers
- Transparent tape
- Metric rulers
- A copy of the size table (with or without all of the columns filled in) and the student instruction sheet for each student or group of students
- A large grapefruit or approx. 5" ball for the Sun for each scale model solar system (A printable 2-D model of the Sun has also been provided.)
- Objects for the planets. Suggestions:
    - poppy seeds or other tiny dark seeds (Mercury, Mars, Pluto)
    - candy sprinkles (Venus, Earth)
    - peppercorns or unpopped popcorn (Uranus, Neptune)
    - marbles or round candies for (Jupiter, Saturn). You can purchase floral craft marbles at craft stores that work well for both size and color.
    - Consider also having some objects such as cherries or small balls (like Super balls) that are significantly larger than a marble and smaller than the large grapefruit, which are too large to represent the planets on this scale.

Materials for Part 2:

- Labeled index cards with objects from Part 1
- Masking tape
- Meter stick(s)
- An open area or straight hallway at least 80 meters (87 yards) long. This is a bit less than the length of a football field.
- A copy of the distance table and the student instruction sheet for each student or group of students
- Cones on which you can place the model Sun and tape planet cards (optional – consider borrowing these from your school gym.)

Note: The use of *italics* indicates information or instructions from the student version

Introduce Scale Factors:

- The **scale factor** for this scale model solar system is **1:10 billion**.
- One good way to talk about scale factors with your students is to discuss maps. You may also want to ask them to name other types of scale models they have seen before (model cars, model rockets, globes, etc.)
- In this scale model, instead of one inch equaling 100 miles, for example, every inch in the model equals 10 billion inches in the real solar system. Similarly, 1 meter in this scale model equals 10 billion meters.

<u>In boxed section top of page 2</u>

Background: Why Use Scale Models?

- *Scientists use models everyday. Models can be conceptual (ex: an atomic nucleus surrounded by orbiting electrons), mathematical (ex: population increase), and scale (ex: model airplanes).*
- *Scale models are a concept that you are already familiar with in the context of model toys (cars, planes, houses, etc.), maps, and globes.*
- *Scale models allow us to explore systems with scales from the microscopic to the astronomical that are beyond the realm of normal human experience.*
- *Scale models of the solar system aid in understanding the relative sizes and distances of objects in the solar system, an important foundation for studying other topics in astronomy.*

Scale models also provide a concrete, hands-on, method of exploring the nature of our solar system in a classroom setting.

Part 1: Scaled Sizes

Key concepts:

- All planets are much smaller than the Sun.
- The Earth is a relatively small planet.

Teacher Instructions:

Provide a selection of objects for the students to choose from to represent the planets.

- If you have fewer than nine types of objects available (plus the object for the model Sun), mention to your students that they can use the same type of object for more than one planet.

- You may wish to also include objects that are too large to represent planets on this scale in the selection you offer the students. Small rubber balls work well as distractors, as do blue marbles.

- Alternatively, have students fill in the size and distance tables as a math assignment (either in class or as homework), and suggest their own objects that can be brought from home, or which you can provide.

1. *Write the name of each planet on an index card. (The Sun doesn't require an index card.)*
    - You may also want to have the students write down facts about each planet on that planet's index card (leaving space for the object that will represent the planet).

2. *Convert the diameters of the Sun and the planets on the SIZE TABLE to the scaled diameter size.*
3. *Using the "scaled diameters" of the Sun and planets from the size table and your ruler, select objects that are approximately the same size as the scaled size for each planet and the Sun.*

    - Have the students calculate out the scaled sizes of objects and/or Earth diameters from the scale factor and real sizes by providing them with the size table with only the real sizes column filled in and the others blank.
    - **To make the calculations easier**, have the students first **convert** the real sizes given in **kilometers to centimeters** by **multiplying by 100,000 cm/km**. Then students will then simply need to **divide the diameter** of each planet **by 10 billion** to obtain the scaled size.
    - **Do the calculation for the size of the scale model Earth for the students as an example.**
    - Make sure that the students understand that the objects need to be close to, but not exactly, the correct size.
    - If you have sufficient classroom time, consider adding the Moon to the card for the Earth. The Moon is 38 mm away from the Earth on this scale, and is about 1/4 the diameter of the Earth (so a poppy seed will work well to represent it.)

4. *Attach the object you have selected for each planet to an index card.*

    - Transparent tape placed over the object works well to attach an object to the index card.

- While students are working, remind them to measure each object selected to see if their choice is reasonable based on the scaled size for each planet in the data table.

5. *Compare the objects you have selected for the Sun and the planets to the object you have selected for the Earth.*

   - This can be used as a follow-up to the scaled sizes portion of the activity.

If you use distracters, go over which objects are reasonable choices to represent each planet with the class, and give the students an opportunity to correct their planet cards. Rubber balls, for example, can be returned to the teacher and replaced with marbles.

Optional: Including Dwarf Planets

Additional data tables, both with and without all of the data filled in are provided for the first objects classified as dwarf planets.

- Ask your students what objects could be used to include these three dwarf planets on the scale model solar system.
- Your students should note that all of the provided objects are too small to use any of the whole objects provided, although half a poppy seed works well for Pluto and Eris. Ceres is so small that a barely-visible speck of dust would make a good object to represent it on the scale model.

Asteroid Belt Interesting Facts:

If all of the asteroids in the asteroid belt, of which Ceres is the largest, were put together into one object, the model of that object in this scale model solar system would not even equal the size half of a poppy seed!

Another way to think about how little material is really in the asteroid belt is to consider it would take at least 1,000 times the total mass of the asteroid belt to equal the mass of the Earth.

Your students are probably aware that Pluto was officially demoted from full planet status in August 2006. But your students probably won't know that the same thing happened to Ceres soon after its discovery in 1801, following the discoveries of many other asteroids in the asteroid belt.

Part 2: Scaled Distances

Key concepts:

- The solar system is mainly empty space.
- The scale of the solar system is immense.
- The small inner planets (Mercury, Venus, Earth, and Mars) are much closer to the Sun than the outer planets.

Before You Begin:

Find a location that is at least **80 m long** where the students **can walk a straight line** from their model Sun. (You will need about ¼ mile to include Neptune, and about 1/3 mile if you want to include Pluto. We recommend you use areas such as long hallways, football practice field, front sidewalk across school parking lot, etc.)

- You can complete the planet walk as a class, have student groups make parallel model solar systems, or have them radiate out from a central point. Consider class management issues and location in deciding which approach to take with your own class(es). Extra adult helpers may be useful if you choose to have students work in small groups.

Prior to beginning this activity with your class, discuss the scale factor of 1:10 billion again. The scale factor is the same for both the sizes of the objects and the distances in the scale model solar system.

- Every step your students take in the scale model is equal to 10 billion steps in the real solar system. For distance in metric units, this means that 10 million km in the model is represented by 1 m in the scale model, as is easy to see in the table of Real and Scaled Distances of the Planets.

Note: All of the distances for the planets are **average** distances from the Sun. The eight planets have fairly circular orbits. For dwarf planets with highly elliptical orbits like Pluto, sometimes the distance will be much shorter (in the case of Pluto, the minimum distance is inside Neptune's orbit) and sometimes much longer.

Teacher Instructions:

1. *Convert the distances from the Sun to the planets on the DISTANCE TABLE to the scaled distance size.*

    - You can give the students a distance table with columns for real distance from the Sun, scaled distance from the Sun, and steps from previous planet already filled out ***or*** you can have the students calculate the scaled distances and steps from the real distances and the scale factor as a math assignment. If time permits, I would recommend the latter.
    - If you require the students to repeat their calculations for each planet, they may find the experience to be tedious. A way to avoid the problem of tedium can be done as a class activity with each group of two or three students working together to calculate the distance between the Sun "their" planet, and the number of one meter steps between "their" planet and the one before it (or the Sun if the chosen planet is Mercury). Each group can then report on their results to the class, and everyone can fill out their tables together.
    - To make the calculations easier, your students can **convert kilometers to meters** by **multiplying by 1000**. The distance of the Earth from the Sun is 150 million kilometers, or 150 billion meters.
    - **Dividing** by the **scale factor of 1 to 10 billion**, the **distance between the model Sun and the model Earth should be 15 meters.**
    - **<u>Note:</u>** some students may find shortcuts that make their calculations easier. These shortcuts are perfectly acceptable.
    - **The version for younger students includes the use of string or yarn that can be attached to each of the planet cards. You may prefer to use this modification with your own students. Then you can hang it up in the room or hallway for later discussions.**

2. *Using a meter stick, practice making a step 1 meter long. Try this a few times until you are comfortable repeating 1 meter steps or very close.*

    - Have students begin the activity by calibrating their steps to meter sticks.

3. *The class will construct our scale model solar system from the scale model Sun to at least as far as Jupiter. <u>How many meters of space do we need for Jupiter? How many to Pluto?</u> (Hint: look at the table of real and scaled distances.)*

    - If there is sufficient space in the location where you will be constructing the model solar systems, you may want to have students continue pacing and laying down cards as far Pluto (or until you run out of space).

- Going to at least Jupiter will allow your students to see the difference in distances between the closely spaced planets in the inner solar system, and the vast distances to the planets in the outer solar system.
- Going out as far as Uranus will be helpful if you will be doing the distance of stars activity.

4. *With your teacher locate a place to make the scale model solar system, place the object representing the scale model Sun at one end.*
5. *Look at the DISTANCE TABLE, and find the column labeled STEPS. The first planet from the Sun is Mercury, and the number of steps is 6. Walk 6 steps (1 meter each) from the model Sun.*
6. *Stop when you reach 6 steps and place the card for Mercury on the ground or taped to a wall at this distance.*

   - If you are outside on a windy day, hold down the cards with small rocks, or tape them to objects like cones.

7. *Look on the DISTANCE TABLE for the number of steps to the next planet. This number of steps is* ***from Mercury to the next planet*** *out from the Sun,* ***not*** *the total number of steps from the Sun to the next planet.*
8. *Walk to the next planet counting the correct number of steps and repeat the procedure you used for Mercury with the index card. Try to keep your path as straight a line as possible.*
9. *Continue counting steps and placing index cards for each planet up to (and including) Jupiter.*

   - When you get to Earth, can have them illustrate the scale distance of the moon also. It is 4 cm from Earth. Listed in the Analysis Questions.

10. *After Jupiter, if room and time allows, continue counting steps and placing cards all the way to Pluto.*

    - If your students are not able to include all of the planets on their distance model, ask them how much farther they would need to walk to include each planet that was left off. Encourage your students to think of neighborhood landmarks that roughly correspond to those distances.

Optional: Adding Dwarf Planets

As with Part 1, additional data tables are provided for the first three dwarf planets classified by the International Astronomical Union. Ask your where on the model Ceres should go. (**Answer:** Between Mars and Jupiter.) Ask them "How much farther past Neptune they would have needed to walk to include Pluto on the model? How much farther to include Eris?" Once again, asking the students to think of landmarks corresponding to these distances will help them visualize adding these objects. You can use a map of the area around your school to facilitate this discussion.

More on Asteroids: Ceres is the largest object in the asteroid belt, and was briefly classified as a planet.

- A common misconception is that the asteroid belt is densely packed with rocky debris**. In fact, on this scale you would need to grind up a fraction of a poppy seed to represent the material in the asteroid belt, and distribute it in a ring between about 30 and 50 meters from the model Sun.**
- Not all asteroids are in the asteroid belt, but a large fraction of them are, and other asteroids are spread even more thinly. Astronomers have found hundreds of thousands of asteroids, but all are tiny compared to a planet. Most asteroids are tens of kilometers across or smaller.
- As your students have discovered if they included dwarf planets in their scale model, even Ceres, the largest object in the asteroid belt, is barely visible on the scale of this Scale Model Solar System. Added together, the asteroids in the asteroid belt have much less material (mass) than any of the planets or the Moon.

More on Pluto: Pluto, recently considered to be a planet, was once thought to be much bigger than it actually is.

- The 2003 discovery of Eris, which is slightly bigger than Pluto, was the primary reason Pluto's status as a planet was re-examined by the International Astronomical Union.
- However, heated debate among astronomers and planetary scientists on the status of Pluto began in 1992 with the discovery of the first (other) Kuiper Belt object.
- By the time Pluto was demoted, more than 1,000 icy objects had been found past the orbit of Pluto.

***Things to think about* (follow-up):** Discuss the following (in italics) with your students. The other information is provided as a supplement for your use:

1. *How does the size of the object for Earth compare to Mars? Jupiter? Sun?*

2. *The Moon in this model is about 4 centimeters (38 millimeters) away from the scale model Earth (and 1/4 the diameter of the scale model Earth).*

   a) *How does this compare to the distances between the Earth and Venus?*

   b) *the Earth and Mars?*

   The Moon is about 30 Earth diameters from the Earth.

3. *How do the distances* ***between planets*** *in the real solar system change as they orbit the Sun?*

   The distances between the planets in the scale model solar system are the minimum distances between the planets, since they are all neatly in a line.

4. *Which does the solar system have more of matter (the Sun, planets, asteroids, etc.) or empty space?*

5. *Light takes about 8 minutes to travel from the Sun to the Earth. What is the speed of light? (Speed = distance/time)*

   - Light (including radio) takes about 8 minutes to travel from the Sun to the Earth.
   - The speed of light is 300,000 km/s
   - Light only takes about 1.2 seconds to travel the distance between the Earth and the Moon.

Supplemental Information for your use:

- The version of this activity for upper elementary students discusses the distances from the nearest star to the Sun, Alpha Centauri.
- For secondary school students, there is a separate activity involving the distances between stars.

This activity is based on the *Colorado Scale Model Solar System* at the University of Colorado at Boulder and associated astronomy exercises compiled by Keith Gleason.