Teacher Guide: Solar System Explorer

Learning Objectives

Students will …

- Compare the masses, radii, and densities of terrestrial planets and gas giants.
- Describe the shape of planetary orbits.
- Discover Kepler's laws:
  - Planets revolve around the Sun in elliptical orbits.
  - Planets speed up as they move closer to the Sun and slow down as they move farther away from the Sun.
  - The cube of a planet's orbital radius is proportional to the square of its period.
- Use Kepler's third law to predict a body's period given its orbital radius.

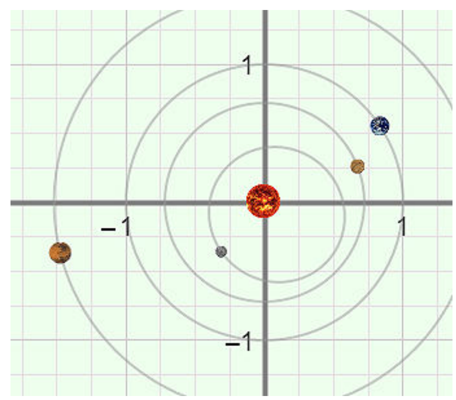
Vocabulary

astronomical unit, dwarf planet, eccentricity, ellipse, gas giant, Kepler's laws, orbit, orbital radius, period, planet, solar system, terrestrial planet

Lesson Overview

The stars and planets have fascinated people for thousands of years. In recent decades, planetary probes have helped us learn more than ever about our closest astronomical neighbors. The *Solar System Explorer* Gizmo™ allows students to observe planets as they travel around the Sun. All distances are shown to scale, and planetary positions correspond to their actual positions for the given date.

Note: The *Solar System* Gizmo explores similar topics to this Gizmo but at a more basic level.



The Sun and the inner planets

The Student Exploration sheet contains three activities:

- Activity A – Students classify planets as terrestrial planets or gas giants.
- Activity B – Students explore the shape of planetary orbits.
- Activity C – Students find the mathematical relationship between a planet's orbital radius and period. [Note: It would be a good idea to review exponents and square roots before assigning this activity to your students.]

Suggested Lesson Sequence

1. **Pre-Gizmo activity: Modeling the solar system** (variable)
   Create a scale model of the solar system in your schoolyard. Use the distance scale 1 meter = 1 AU. (One astronomical unit, or AU, is equal to the Earth-Sun distance.) To include Neptune and Pluto you will need a space that is 30–40 meters long. The orbital radius of each planet is given in the *Solar System Explorer* Gizmo. Along with photos or drawings of the planets, you could include images or models that are to scale.

2. **Prior to using the Gizmo** (10 – 15 minutes)
Before students are at the computers, pass out the Student Exploration sheets and ask students to complete the Prior Knowledge Questions. Discuss student answers as a class, but do not provide correct answers at this point. Afterwards, if possible, use a projector to introduce the Gizmo and demonstrate its basic operations. Demonstrate how to take a screenshot and paste the image into a blank document.

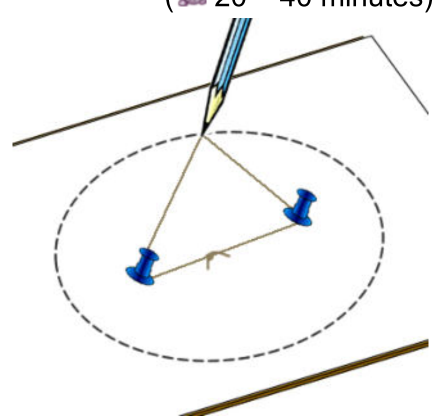
3. **Gizmo activities** (15 – 20 minutes per activity)
Assign students to computers. Students can work individually or in small groups. Ask students to work through the activities in the Student Exploration using the Gizmo. Alternatively, you can use a projector and do the Exploration as a teacher-led activity.

4. **Discussion questions** (15 – 30 minutes)
As students are working or just after they are done, discuss the following questions:

    - Why are inner planets composed mostly of rock and metal, while the outer planets are composed mostly of gas? [See the **Appendix** on the last page of this document for an explanation.]
    - How would you describe the eccentricity of most planetary orbits?
    - Why do planets move most quickly when they are closest to the Sun and most slowly when farthest away? [The Sun's gravity causes planets to accelerate as they move closer to the Sun and to slow down as they move away from the Sun.]
    - Ceres is a dwarf planet in the asteroid belt between Mars and Jupiter. Ceres has a period of 4.60 Earth years. According to Kepler's third law, what is its orbital radius? [2.77 AU]
    - Pluto was closer to the Sun than Neptune from 1979 to 1999. Use the Gizmo to find the next time Pluto will be closer to the Sun than Neptune. [Around 2227]
    - NASA scientists are researching the possibility of sending astronauts to Mars. When would be a good time to do this?

5. **Follow-up activity: Drawing ellipse** (20 – 40 minutes)
To draw an ellipse you will need string, tacks, a pencil, a sheet of paper, and a sheet of thick cardboard. Follow these steps to create an ellipse:

    - Tie a loop of string.
    - Push two tacks through the paper and into the cardboard, as shown at right.
    - Loop the string over the tacks.
    - Draw the ellipse by pulling the string loop taught with a pencil and tracing around the two tacks.

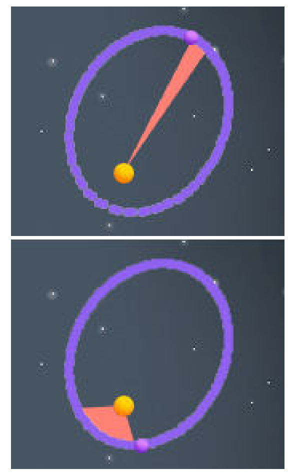


For each ellipse that students draw, ask them to calculate its eccentricity by dividing the distance between the tacks (each tack is a *focus* of the ellipse) by the width of the ellipse. Challenge students to create ellipses that match the shapes of planetary orbits, as well as the orbits of dwarf planets, comets, and other objects in the solar system.

Scientific Background

The six closest planets are all visible to the naked eye and were observed by ancient civilizations. The word “planet” is derived from the Greek word meaning “wanderer” because planets move from night to night against a backdrop of relatively stationary stars.

For many centuries, most astronomers accepted Claudius Ptolemy’s geocentric model, in which the Sun and planets orbited Earth. Although Ptolemy’s model was usually able to accurately predict the positions of the planets, it was physically improbable because each planet’s orbit included one or more small loop-the-loops, called *epicycles*. In the mid-1500s, Nicolaus Copernicus proposed a *heliocentric*, or Sun-centered, model of the solar system. This model gradually gained scientific acceptance in the following centuries.



The German astronomer Johannes Kepler (1571–1630) was an early advocate of the heliocentric model. Kepler sought to describe planetary orbits mathematically. Working with a wealth of planetary observations compiled by his mentor Tycho Brahe, Kepler eventually discovered that all planetary orbits were elliptical in shape, with the Sun at one focus. Kepler next discovered that planets speed up as they get closer to the Sun in their orbit and then slow down as they move farther away. Kepler discovered that if you drew a line from the planet to the Sun, the line would sweep out across equal areas in equal times. In the diagram at right, each pink section represents the area swept out in 100 days. The two pink sections have the same area. (Note: These images were created using the *Orbital Motion – Kepler’s Laws* Gizmo.)

Kepler’s third law states the relationship between a planet’s *period* (T), the amount of time it takes to orbit the Sun, and its *orbital radius* (R), or mean distance from the Sun. Kepler found that the square of the period is proportional to the cube of the orbital radius. If the period is measured in Earth years and the orbital radius is measured in astronomical units (AU), the squared period is almost exactly equal to the cubed radius: $T^2 = R^3$.

Over the next few centuries, our knowledge of the solar system was expanded by the discovery of Uranus (1781), Neptune (1846), and Pluto (1930). In the past decade, several new objects have been observed beyond Pluto. The largest of these, Eris, is larger than Pluto. In 2006, astronomers agreed to classify these objects, along with Pluto and Ceres, as *dwarf planets*.

Selected Web Resources

Solar system scale model activity: http://www.exploratorium.edu/ronh/solar_system/
Drawing ellipses activity: http://www.mathopenref.com/constellipse1.html
Our solar system: https://solarsystem.nasa.gov/planets/
Geocentric and heliocentric systems: http://www.astro.psu.edu/users/rbc/a1/lec4n.html
Dwarf planets:
http://www.windows.ucar.edu/tour/link=/our_solar_system/dwarf_planets/dwarf_planets.html

Related Gizmos:
Solar System: http://www.explorelearning.com/gizmo/id?636
Comparing Earth and Venus: http://www.explorelearning.com/gizmo/id?374
Orbital Motion – Kepler’s Laws: http://www.explorelearning.com/gizmo/id?586

Appendix: Origin of the solar system

The planets in our solar system can be divided neatly into two groups of four. The four inner planets (Mercury, Venus, Earth, and Mars) are relatively small, dense, and rocky. These are classified as *terrestrial planets*. Separated from the inner planets by the *asteroid belt*, the outer planets (Jupiter, Saturn, Uranus, and Neptune) are relatively large and composed mainly of gas. These are the *gas giants*.

The contrast between terrestrial planets and gas giants originated when our solar system formed about 4.6 billion years ago. Most scientists agree that our solar system formed from a large cloud of gas and dust, or *nebula*, left behind by the explosion of a massive star.

A disturbance of some kind, such as a shock wave from a nearby supernova, probably caused the cloud to become unstable and start to collapse under its own gravity. As the cloud of gas and dust collapsed, it also began to spin. This caused the cloud to become a *protoplanetary disk*, such as the one shown at right.

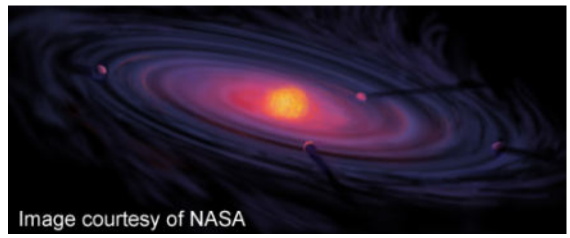


Image courtesy of NASA

Within the protoplanetary disk, most of the gas and dust collected in the center and formed a *protostar*. Gravity pulled the molecules in the protostar together, causing them to collide with one another and heat up. Eventually, the protostar became hot enough to start the process of nuclear fusion and become a star. Around the developing star, small planets (*protoplanets*) started to form as particles began to stick together. Eventually the protoplanets grew large enough to attract particles through their own gravity.

In the regions closest to the Sun, temperatures were too hot for gases such as water vapor and methane to condense. As a result, the planets that formed here were smaller and rocky in composition. Over time, many of these rocky protoplanets collided and merged, resulting in four terrestrial planets and an asteroid belt. Farther from the Sun, it was cold enough for gases to condense and accrete onto the developing planets. Eventually, some of these planets grew large enough to attract the lightest gases, hydrogen and helium. In this way, Jupiter, Saturn, Uranus, and Neptune formed.

As the Sun matured into a star, it emitted a stream of ions known as a *solar wind*. The powerful solar wind blew the remaining gas and dust from the solar system. This ended the growth of the planets.