Voyage: A Journey through our Solar System

Grades 5-8

Lesson 5: Round and Round We Go – Exploring Orbits in the Solar System

On October 17, 2001, a one to ten billion scale model of the Solar System was permanently installed on the National Mall in Washington, DC. The *Voyage* exhibition stretches nearly half a mile from the National Air and Space Museum to the Smithsonian's Castle Building. *Voyage* is a celebration of what we know of Earth's place in space and our ability to explore beyond the confines of this tiny world. It is a celebration worthy of the National Mall. Take the *Voyage* at www.voyageonline.org, and consider a *Voyage* exhibition for permanent installation in your own community.

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.

Voyage and *Journey through the Universe* are programs of the National Center for Earth and Space Science Education, Universities Space Research Association (www.usra.edu). The Voyage Exhibition on the National Mall was developed by Challenger Center for Space Science Education, the Smithsonian Institution, and NASA.

Lesson 5: Round and Round We Go—Exploring Orbits in the Solar System

Lesson at a Glance

Lesson Overview

In order to have an appreciation for the complexity of the Solar System, students must understand that the Solar System is a dynamic system with many moving parts. Students explore the nature of circles versus ellipses and how they relate to orbits in the Solar System. After creating a model of the Solar System, in which students plot orbits of Solar System objects around the Sun, students begin to understand how orbits can be used to help categorize objects in the Solar System.

Lesson Duration

Two or three 45-minute classes

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.
- Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.
- Gravity is the force that keeps planets in orbit around the sun and governs the rest of the motion in the solar system. Gravity alone holds us to the earth's surface and explains the phenomena of the tides.

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 great 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.

Essential Questions

- What is an ellipse?
- What is the nature of orbits of various Solar System objects?

Concepts

Students will learn the following concepts:

- A circle is an ellipse with both foci located at the same point.
- The orbits of planets (and most other objects in the Solar System) around the Sun are ellipses with the Sun located at one focus.
- The shapes of the orbits of comets are different from the orbits of planets.

Objectives

Students will be able to do the following:

- Draw a circle and an ellipse, and understand their similarities and differences.
- Plot planetary orbits and compare them to orbits of other objects around the Sun.
- Classify Solar System objects based on their orbits.

Science Overview

As long as people have observed planets, they have sought to explain their movement in the sky. Because the classical planets–Mercury, Venus, Mars, Jupiter and Saturn–can be seen easily with the naked eye, this quest goes back as far as history can be traced. In ancient times, people usually thought that the Earth was at the center of the Universe, with the Sun, the Moon, and the planets moving around the Earth in perfect circles. However, this system was not able to explain the observed motions of the planets properly. The breakthrough in explaining the motions of the planets came in the 16th and 17th centuries, when Nicolaus Copernicus (1473-1543) introduced the heliocentric model, which placed the Sun at the center of the Solar System (which then was thought to be pretty much the whole Universe), and when Johannes Kepler (1571-1630) suggested that using ellipses instead of circles is the best way to explain the motions of the planets.

Ellipses and Circles

An ellipse is a geometrical shape that looks much like a squashed circle. To draw one, drape a loop of string around two fixed points that are placed on a piece of paper (see Figure 1). With a pencil, draw a curve by pulling the string taut and sweeping it around the paper. The places where the two points are located are called the ellipse's foci (plural of focus). The length of the long axis of the ellipse is called its major axis. The smaller axis, perpendicular to the major axis, is called the minor axis (see Figure 2).

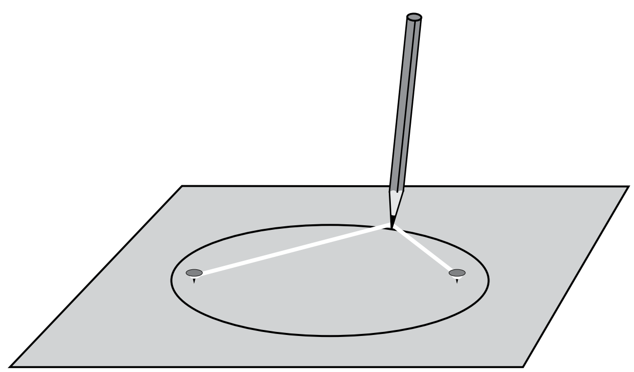


Figure 1: Drawing an ellipse with string and tacks

How stretched out an ellipse is can be described by a quantity called eccentricity. An ellipse's eccentricity is calculated by dividing the distance between the ellipse's foci by the length of the major axis. In other words

$$\text{eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}}$$

If an ellipse has an eccentricity of zero, it is a perfect circle. In this case, the two foci are located in the same place: the circle's center. If an ellipse has an eccentricity close to one, it is very long and narrow. Ellipses cannot have eccentricities greater than or equal to one, or less than zero.

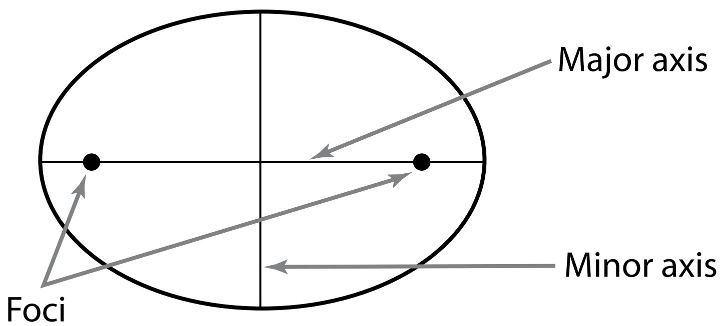


Figure 2: The properties of an ellipse can be described by the location of its foci and the lengths of its major and minor axes.

Kepler's Laws

Johannes Kepler (1571-1630) was a German astronomer who strived to find a mathematical way to describe the planets' movements in space. By the 17th century it was clear that the explanation of planetary motions using perfect circles was not adequate. In 1609, Kepler stated his first of three laws of planetary motion: the orbit of each planet is an ellipse, with the Sun located at one focus. While Kepler's First Law only mentions planets, it also applies to other objects that orbit the Sun, such as comets, asteroids (sometimes called minor planets), icy worlds in the outer parts of the Solar System called Kuiper Belt Objects, and even tiny dust particles. Note that objects that orbit another body and not the Sun (such as the planets' moons or the particles that make up the rings of Jupiter, Saturn, Uranus and Neptune) orbit their host body (planet) in elliptical orbits.

Kepler's other two laws further define the orbits of the planets. The second law states that if an imaginary line is drawn from the planet to the Sun, the size of the area of the ellipse that the line moves over as the planet moves on its orbit during a given time is the same, regardless of where the planet is on its orbit. This means that planets move faster in their orbit when they are closer to the Sun and slower when they are farther away (see Figure 3).

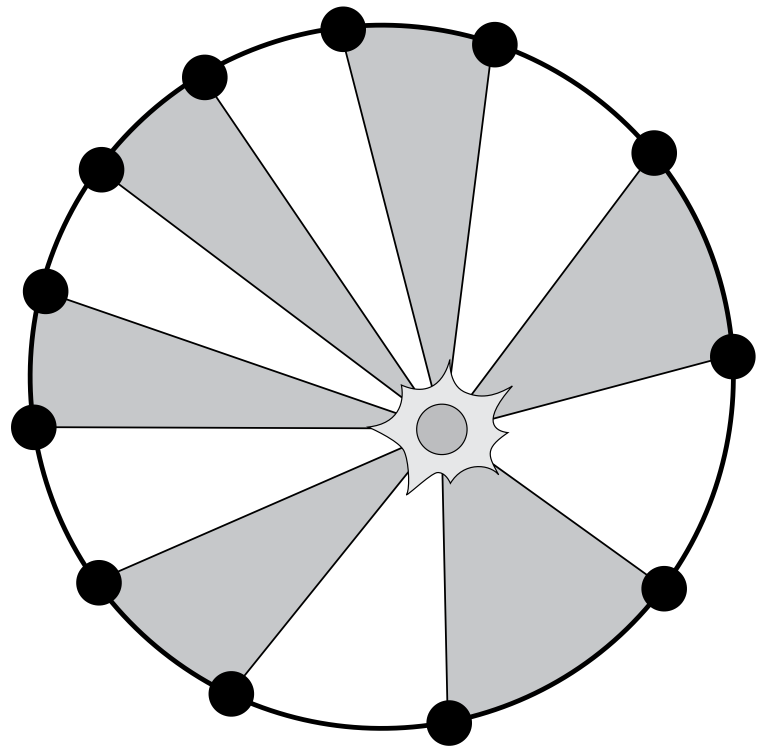


Figure 3: Kepler's Second Law states that the amount of area swept out during any time interval of a planet's orbit is the same, regardless of where the planet is on its orbit. Each black dot in the figure above represents a planet at equal time intervals on its orbit around the Sun. Therefore, according to Kepler's Second Law, each of the shaded regions are equal in area. Note that this means the planet must move faster in its orbit when it is closer to the Sun than when it is farther away. NOTE: Not to scale.

Kepler's third law states that a planet's orbital period (the time it takes to orbit the Sun once) is related to its major axis: the square of the period (T_{yr}) is proportional to the cube of half of the length of the orbit's major axis (A_{AU}), and roughly equal if the length of the period is expressed in Earth years, and the length of the major axis in AU (one astronomical unit—AU—is the average distance between the Earth and the Sun and is equal to 150 million km, or 93 million miles.) That is,

$$(T_{yr})^2 \approx (1/2 \times A_{AU})^3.$$

For Earth, this relationship is exact (1 Earth year, 1 AU). The theoretical basis for Kepler's laws was explained by Sir Isaac Newton (1642-1727) when he presented his theory of gravitation—the planetary orbits are a manifestation of the gravitational interaction between the planets and the Sun.

Planetary Orbits vs. Cometary Orbits

In general, the eccentricity of all planetary orbits is small; they orbit the Sun in almost perfect circles. The two exceptions to this are Mercury and Pluto. Mercury's orbit is heavily influenced by its close proximity to the Sun, and this may explain Mercury's high orbital eccentricity. Pluto's high eccentricity is similar to those of some asteroids, comets, and Kuiper Belt Objects. Some scientists actually have suggested that perhaps Pluto is not a real planet at all but just a very large Kuiper Belt Object. This suggestion is not generally accepted, however. Not enough is known of the objects in the outer Solar System to warrant changing the status of Pluto from a planet to something else, especially since it has been considered a planet since its discovery in 1930. Any change in Pluto's status at this point would be premature. In fact, International Astronomical Union, which is the body that decides on the classification of Solar System objects, gave a decision in 1999 clarifying Pluto's position as a planet and has no plans to revisit the issue in the foreseeable future. The issue became a little more complicated in 2005 when astronomers reported finding an object in the Kuiper Belt that is larger than Pluto. Is the object the tenth planet in the Solar System? Or does this mean that Pluto should not be considered a planet after all, especially if there were to be other objects just as big in the Kuiper Belt? The question remains open (at least as of this writing in September 2005).

The orbits of comets are in general quite eccentric, approaching values close to 1. The orbits of planets and comets define the two orbital extremes in the Solar System. The orbits of the other objects, such as asteroids and Kuiper Belt Objects, fit between these two extremes.

Another important characteristic of orbits is their inclination—that is, how much the plane in which they orbit the Sun are is angled with respect to the plane of Earth's orbit. The inclination of most of the planets is low: they orbit the Sun in pretty much the same plane. The inclinations of cometary orbits vary a great deal, again providing the end piece to the range of orbits in the Solar System. For the present purposes, the focus is on the shape of orbits instead of inclination, but it is good to remember that the orbits are located in three-dimensional space instead of just one plane.

Orbital parameters for planets,
as well as sample comets, asteroids and Kuiper Belt Objects

	Distance from the Sun *(AU; Earth-Sun distance)*	Length of major axis *(AU; Earth-Sun distance)*	Orbital eccentricity	Orbital period *(Earth years)*
PLANETS				
Mercury	0.387	0.774	0.2056	0.241
Venus	0.723	1.446	0.0067	0.615
Earth	1	2	0.0167	1
Mars	1.524	3.048	0.0935	1.881
Jupiter	5.204	10.408	0.0489	11.862
Saturn	9.582	19.164	0.0565	29.457
Uranus	19.201	38.402	0.0457	84.011
Neptune	30.047	60.094	0.0113	164.79
Pluto	39.482	78.964	0.2488	247.68
SAMPLE COMETS				
Halley	17.94	35.88	0.967	76.1
Encke	2.21	4.42	0.847	3.30
Wild 2	3.44	6.88	0.540	6.39
Hale-Bopp	250	500	0.995	4,000
Hyakutake	1,165	2,330	0.9998	40,000
SAMPLE KUIPER BELT OBJECTS				
Quaoar	43.500	86.999	0.0349	287
Ixion	39.583	79.165	0.241	249
Varuna	43.007	86.014	0.0512	282
Chaos	45.651	91.301	0.104	308
SAMPLE ASTEROIDS				
Ceres	2.767	5.534	0.0789	4.60
Pallas	2.774	5.548	0.2299	4.61
Juno	2.669	5.338	0.2579	4.36
Vesta	2.362	4.724	0.0895	3.63

(Data for planets, comets, and asteroids from NASA's National Space Science Data Center, http://nssdc.gsfc.nasa.gov/planetary; data for Kuiper Belt Objects from http://www.ifa.hawaii.edu/faculty/jewitt/kb.html and http://cfa-www.harvard.edu/~graff/Ephemerides/Distant/)

NOTES:

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

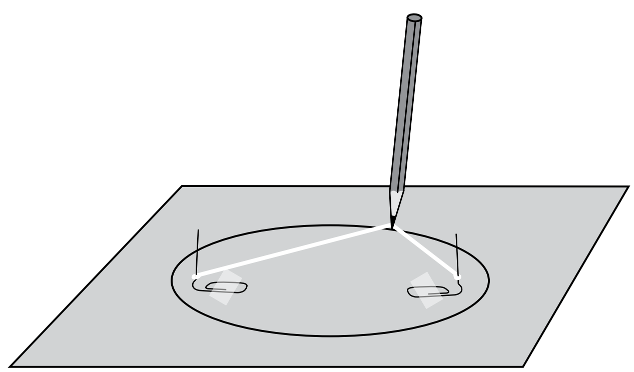
- 2 paper clips
- Transparent tape
- A blank overhead transparency
- Overhead projector
- Overhead marker
- 1 piece of string, approximately 25 cm (10 in) long

Student Materials

- (Optional): One sheet of notebook paper

Preparation & Procedures

1. Create the transparency device you will need for the Warm-up & Pre-assessment. To do so, lie two paper clips flat on the table, and bend the end of the wire straight up in the air (see figure below). Firmly tape one paper clip to central lower part of the transparency.



2. Set up the overhead projector. Ask the students to raise their hands if they think they can draw a perfect circle on the overhead. Ask them what would they need to make it accurate? (*Desired answer: they would need a sturdy point in the middle, and some way to keep the marker at the same distance from the sturdy point, like a string connecting them*)

3. Place the transparency with one paper clip on the overhead projector. Tie each end of the string around the paper clip wire, place the marker in the loop, pull taut, and create a circle on the transparency.

4. Ask the students what would happen if you taped another paper clip to the transparency, tied the string around both paper clips, and drew the figure the same way. What shape would you make? Take a few suggestions—or have students draw their suggestions individually on a piece of paper—and then tape the other paper clip a few inches above the first on the transparency. Tie one end of the string to each of the paper clips, pull the string taut with the marker, and move the marker from side to side, keeping the string taut, in order to create half of the ellipse. You will need to put the marker on the other side of the string in order to create the other half of the ellipse.

5. Have students predict what would happen if you moved the clips closer together or further apart. Explain that they will experiment with ellipses to find out in Activity 1.

Teaching Tip

Make sure that the string does not slide underneath the paper clip or rise up against it when you draw the circle. You can prevent this by making sure you tape the paper clip to the transparency right at the base of the rising arm and place a strip of tape on the arm, leaving its base bare so the string can loop around but not rise or fall as you draw.

Activity 1: Ellipses are Eccentric!

Students will learn how to draw ellipses based on the major axis and the distance between the foci.

Student Materials
(per student or pair of students)

- 2 paper clips
- Transparent tape
- Pen or pencil
- String
- Scissors
- A piece of paper
- Student Worksheet 1

Preparation & Procedures

1. Place students in pairs.

2. Review the terminology with the students. They will be creating an ellipse. The places where the two paper clips are located are called the ellipse's foci (plural of focus). The length of the long axis of the ellipse is called its major axis. The small axis perpendicular to the major axis is called the minor axis. (See Figure 2 in *Science Overview* or Figure S2 in Student Worksheet 1.)

3. Have students complete Student Worksheet 1. Make sure that they set up their paper clips and ellipse templates correctly. After the activity is completed, use the questions in the *Reflection & Discussion* section to lead the students to the understanding of eccentricity. Then have students complete Student Worksheet 2.

Reflection & Discussion

1. As a class, discuss the results. Be sure to discuss an important property of ellipses: the sum of the distances to the foci remains the same no matter where the point is on the ellipse. You can use the following facilitation:

Ask the students what remains constant as the circle was drawn in the *Warm-up & Pre-assessment*. (*Desired answer: the radius*) How did we ensure that to be the case? (*Desired answer: the length of the string is the same as the radius of the circle, and the length of the string did not change*) Did the length of the string change when we were creating the ellipses? (*Desired answer: no*) Did the distance to the foci change? (*Desired answer: yes*) Then what does the length of the string represent? (*Desired answer: the sum of the distances to the foci*) Therefore, although the distance to each focus varies at different points along the ellipse, the sum of the distances to the foci remains the same no matter where the point is on the ellipse, and the sum is the length of the string.

2. Discuss how eccentricity is the property that decides the shape of the ellipse. You can use the following facilitation, which follows the questions in their worksheet: What happened when the two foci were placed further apart? (*Desired answer: the ellipse was less circular*) What happened when the string became shorter? (*Desired answer: the ellipse was less circular*) What would happen if the foci were very far apart, but the string was very long? (*Desired answer: the ellipse would be more circular.*) What is the real property that decides the shape of the ellipse? (*Desired answer: the ratio of the distance between the foci and the length of the string*) Tell the students that this ratio has a name, and is called the eccentricity of the ellipse.

Transfer of Knowledge

Refer to the *Transfer of Knowledge* section in Student Worksheet 2.

Placing the Activity Within the Lesson

Discuss with students how planets orbit the Sun, and what is meant by the word "orbit."

Discuss how although Earth's orbit is not perfectly round, it is very close. But in fact, Earth (and everything else in the Solar System) travels in an ellipse around the Sun. In Activity 2, students will model how the objects in the Solar System orbit the Sun.

Teaching Tip

Depending on the level of your students, you can let them manipulate their string and paper clips to help them with the *Transfer of Knowledge* questions, or you can have them figure out the questions without visual help.

Round and Round We Go
Lesson at a Glance
Science Overview
Conducting the Lesson
Warm Up & Pre-Assessment
Activity 1: Ellipses are Eccentric!
Activity 2: The Eccentricities of Solar System Objects: How Crazy Are They?
Lesson Wrap-Up
Resources

Assessment Criteria for Activity 1

5 Points

- Student Worksheet 1 is complete and accurate.
- Questions were answered completely and accurately in Student Worksheet 2.

4 Points

- Student Worksheet 1 is complete and mostly accurate.
- Questions were answered completely and mostly accurately in Student Worksheet 2.
- Student drew an accurate ellipse in Student Worksheet 2

3 Points

- Student Worksheet 1 is complete and somewhat accurate.
- Questions were answered completely and somewhat accurately in Student Worksheet 2.
- Student drew an accurate ellipse in Student Worksheet 2.

2 Points

- Student answered most of the questions in Student Worksheet 1, and answers are somewhat accurate.
- Student answered most of the questions in Student Worksheet 2, and the answers are somewhat accurate.
- Student drew an almost accurate ellipse in Student Worksheet 2.

1 Point

- Student Worksheet 1 is somewhat accurate.
- Student answered several of the questions in Student Worksheet 2, and the answers are somewhat accurate.
- Student attempted to draw an ellipse in Student Worksheet 2.

0 Points

- No work completed.

Notes on Activity 1:

Activity 2: The Eccentricities of Solar System Objects: How Crazy Are They?

Students will plot the elliptical orbits of some of the Solar System objects and examine how the orbits of the planets are different from one another and also different from the rest of the objects in the Solar System.

Student Materials
(per student or pair of students)

- Transparent tape
- Protractor
- Meter stick or a long ruler
- Calculator
- 2 paper clips
- 1 piece of string, at least 375 cm (148 in) in length
- Pen or pencil (Optional: 8 different colors)
- 1 piece of paper, approximately 50 cm × 50 cm (20 in × 20 in) – poster board size paper works well
- Student Worksheet 3

Preparation & Procedures

1. Each student or pair of students will need a desk or table at least as large as their poster board sized paper. (Alternatively, they could use the floor if there is not enough desk space.)

2. The students will cut up the string in Activity 2 to draw the orbits of several objects in the Solar System. The length of string listed above is enough for all objects as well as 6 cm (2.4 in) to tie a knot in each end of each piece of string. If the students require more string to tie the knots, adjust the total length of the string accordingly. Students will draw the orbits of eight objects.

3. Discuss with the students how the Sun dictates the orbits of all Solar System objects. For example, ask the students: Why does the Earth (and everything else in the Solar System) orbit the Sun? (*Desired answer: the Sun makes up 99.8% of the mass in the Solar System, and therefore dictates the motion of all other objects in it*) Discuss with students how Johannes Kepler discovered that the planets orbit the Sun in an ellipse. Where do the students think the Sun is located? (*Desired answer: at one of the foci; see* Science Overview *for more information*) Discuss with students how the planetary motions can be explained with the theory of gravitation.

4. Models can help us explore things that may otherwise be too large (or small) for us to understand. Based on what they know from Activity 1, ask students what they would need to know about a planet's orbit in order to make a scale model. (*Desired answer: they would need to know the major axis and the eccentricity of its orbit. They would also need to know the scale at which they are to make the model, and the orbit's orientation in space.*)

5. Have students work individually or in pairs to explore orbits in the Solar System by following the procedures in Student Worksheet 3. However, each student should be responsible for answering the questions on Student Worksheet 3 individually.

Reflection & Discussion

1. Discuss the orbits of the objects with students. What did they notice is common to all planets? (*Desired answer: all orbits are elliptical, some more than others*) How are they oriented with respect to one another? (*Desired answer: they all lie on different axes*) How are cometary orbits different? (*Desired answer: they are much more elliptical than planetary orbits*) Is there anything that surprises them?

2. Remind students that they have created a two-dimensional model of the orbits in the Solar System. In reality, there is also the third dimension ("up" or "down") for the orbits—not everything in the Solar System orbits the Sun in exactly the same plane as Earth does. One way to imagine this effect is to think each orbit is drawn on a different piece of paper and then the papers are tilted with respect to each other. The angle that describes the tilt is called "inclination"—but it is not the topic of this lesson. The reason for reminding students about this effect is to make sure they realize that the orbits are all in three-dimensional space, not in one nice place as the piece of paper in which they made their model. The scale of this two-dimensional model is $1 : 1.496 \times 10^{13}$; that is, 1 AU in reality equals 1 cm in the model.

3. Discuss with students that even within a class of objects ("asteroids" or "Kuiper Belt Objects") there is variation in the orbital characteristics. For example, asteroid Ceres has a low eccentricity (0.0789), while Pallas (the orbit of which the students drew) has a higher eccentricity (0.2299).

Transfer of Knowledge

Have the students plot an object whose orbit has an eccentricity of 0.0347 and whose major axis is 86.622 AU long. Ask them to which group it belongs, planets or Kuiper Belt Objects. (*This is the orbital information for Quoar, a large Kuiper Belt Object.*)

Assessment Criteria for Activity 2

5 Points
- Student accurately completed Table 1 in Student Worksheet 3.
- Student accurately drew the orbits of the objects described in Table 1 of Student Worksheet 3.
- Student accurately answered the questions on Student Worksheet 3.
- Student accurately plotted and classified the orbit of the mystery object (Quoar).

4 Points
- Student accurately completed Table 1 in Student Worksheet 3.
- Student accurately drew the orbits of the objects described in Table 1 of Student Worksheet 3.
- Student accurately answered most questions on Student Worksheet 3.
- Student accurately plotted and classified the orbit of the mystery object (Quoar).

3 Points
- Student completed mostly accurately Table 1 in Student Worksheet 3.
- Student mostly accurately drew the orbits of the objects described in Table 1 of Student Worksheet 3.
- Student accurately answered most of the questions on Student Worksheet 3.
- Student accurately plotted and classified the orbit of the mystery object (Quoar).

2 Points
- Student accurately filled in part of Table 1 in Student Worksheet 3.
- Student drew accurately the orbits of some of the objects described in Table 1 of Student Worksheet 3.
- Student accurately answered some of the questions on Student Worksheet 3.
- Student accurately plotted and classified the orbit of the mystery object (Quoar).

1 Point
- Student attempted to fill in part of Table 1 in Student Worksheet 3.
- Student attempted to draw the orbits of the objects described in Table 1 of Student Worksheet 3
- Student attempted to answer the questions on Student Worksheet 3.
- Student attempted to plot and classify the orbit of the mystery object (Quoar).

0 Points
- No work completed.

Extensions

Have students research orbits in other contexts. How do the moons go around planets? How eccentric are their orbits? What about the rings of the giant outer planets? Do stars go around the center of the Milky Way galaxy in elliptical orbits?

Placing the Activity Within the Lesson

By plotting the orbits of the Solar System objects, students should understand the layout of the Solar System and that the definition of "planets" is arbitrary if only orbital characteristics are used.

Notes on Activity 2:

Lesson Wrap-Up

Lesson Closure

Discuss with students the different kinds of orbits in the Solar System: planetary vs. cometary orbits. Discuss how the different kinds of objects "see" the Solar System—the planets which are pretty much at the same distance from the Sun during their orbit, vs. the comets which spend much of their time in the frigid outer Solar System and then swing in to be heated up by the Sun.

Students use previous knowledge, as well as what they now know about orbits in the Solar System, to discuss whether Pluto should be considered a planet.

Transfer of Knowledge for the Lesson

Have the students research the discovery of Pluto, and why it was classified as a planet. Have them make a decision as to whether or not they think Pluto should be classified as a planet. Have students write a short essay to support their opinion. Students should use information about Pluto's orbit that they learned in class as well as its composition and history as support in their essay. Have students form teams according to which side of the issue they are on, and have the teams debate the topic during class. Have students use the points in their essay to argue their side.

Sample argument: Pluto is an interesting planet, since it does not seem to fit comfortably within the family of planets in the Solar System. The other planets (with the exception of Mercury) all orbit the Sun in almost perfect circles. Pluto's eccentricity is quite high, similar to those of some asteroids, comets, and Kuiper Belt Objects. Pluto does not fit neatly in either of the two main categories of planets. Like a terrestrial planet, it is small, but, because it probably is made of a mixture of rock and ice, its density is low, like that of a Jovian planet. It most certainly is not a gas giant, but it is in the outer part of the Solar System. It has been suggested that Pluto may be just a very large Kuiper Belt Object and not a real planet at all. However, because of its historical association as one of the nine planets in the Solar System, it is unlikely that Pluto will be demoted from the ranks of the planets anytime soon; that would require a much better understanding of the outer reaches of the Solar System and the objects residing there than we currently have.

You can have students read the International Astronomical Union's (IAU) press release on Pluto's status as a planet (see *Internet Resources & References* section) and see how their arguments compare with IAU's decision.

Assessment Criteria for the Lesson

5 Points
- All worksheets were completed accurately and thoroughly.
- Student's *Transfer of Knowledge* essay presented their information convincingly.
- Student's arguments during the debate were well supported.

4 Points
- All worksheets were completed thoroughly.
- Student's *Transfer of Knowledge* essay presented their information with ease.
- Student's arguments during the debate were adequately supported.

3 Points
- All worksheets were completed.
- Student's *Transfer of Knowledge* essay presented most information with ease.
- Student's arguments during the debate were supported.

2 Points
- All worksheets were mostly completed.
- Student's *Transfer of Knowledge* essay showed adequate understanding of the topic.
- Student's arguments during the debate were supported, but relevance was questionable.

1 Point
- Student attempted to answer all worksheets.
- Student's *Transfer of Knowledge* essay showed little understanding of the topic.
- Student's arguments during the debate were not supported.

0 Points
- No work completed.

Extensions for the Lesson

Kepler's Third Law states that the square of the time it takes an object to orbit the Sun is proportional to the cube of half of the length of the orbit's major axis, and approximately equal if the length of the year is in Earth years, and the length of the major axis is in AU (one AU = one astronomical unit = the average distance between the Earth and the Sun). In other words

$$(\text{Orbital Period in Years})^2 \approx (1/2 \times \text{Length of Major Axis in AU})^3$$

Using this formula, have students calculate the periods of the planets and comets in this activity.

Curriculum Connections

Language Arts: Review the format of a debate and have students practice expressing and supporting their opinions respectfully.

History: During the *Transfer of Knowledge for the Lesson* section, students research the history of the discovery of Pluto. Have them research the discovery of Uranus and Neptune, or the formulation, early controversy, and eventual acceptance of the Heliocentric Theory.

Lesson Adaptations

Gifted and Talented:
Have the students calculate their scale model by looking up the information about the planets and then deciding what scale would work best for their purposes, instead of using the $1 : 1.496 \times 10^{13}$ (1 AU = 1 cm) scale model provided in Student Worksheet 3.

Have students find the orbital inclination of the planets and create a 3-D model of the Solar System. They could use wire to represent the orbits of the planets rather than drawing them.

ESL: Have students create a poster which visually supports their opinion regarding Pluto's status as a planet, instead of writing an essay.

NOTES:

Resources

Internet Resources & References

Student-Friendly Web Sites:

Astro for Kids
    www.astronomy.com/asy/default.aspx?c=a&id=1091
Astronomy for Kids
    www.frontiernet.net/~kidpower/astronomy.html
KidsAstronomy.com (Solar System)
    www.kidsastronomy.com/solar_system.htm
Online Explorations
    amazing-space.stsci.edu/resources/explorations/
Manipulating Ellipses
    chickscope.beckman.uiuc.edu/explore/eggmath/shape/pins.html
NASA Kids
    kids.msfc.nasa.gov/SolarSystem/
Star Child
    starchild.gsfc.nasa.gov
Welcome to Astronomy for Kids!
    www.dustbunny.com/afk/

Teacher-Oriented Web Sites:

American Association for the Advancement of Science, Project 2061
    www.project2061.org/tools/benchol/bolframe.htm
The Busy Teacher's Web site
    www.ceismc.gatech.edu/busyt/
International Astronomical Union: The Status Of Pluto Press Release
    www.iau.org/PlutoPR.html
Kuiper Belt (data for orbits; further information on Kuiper Belt Objects)
    www.ifa.hawaii.edu/faculty/jewitt/kb.html
NASA Quest
    quest.arc.nasa.gov/sso/teachers/
National Science Education Standards
    www.nap.edu/html/nses/
National Space Science Data Collection (NSSDC) (data for orbits):
    nssdc.gsfc.nasa.gov/planetary/
The Nine Planets
    www.nineplanets.org/
Pro-Teacher
    www.proteacher.com/110066.shtml
Star Date
    stardate.org/resources/ssguide/
Voyage Online
    www.voyageonline.org

Teacher Answer Key

Student Worksheet 1

1. Further apart: ellipse becomes more stretched out. Closer together: ellipse becomes more circular.

2. Smaller: ellipse becomes more "squashed." Longer: ellipse becomes more circular.

3. Yes. You would need a very short string.

4. Yes. You would need a very long string.

5. It is a combination of the two. (More specifically, it is the ratio of the two, but the students cannot be expected to know this yet.) If the length of the string is much longer than the distance between the foci, you will get a circular shape. If the values are similar, then you will get a very elliptical shape.

Student Worksheet 2

1. a. A circle

   b. Eccentrity = 0

2. a. A line

   b. Eccentricity = 1. No ellipse can really have this eccentricity.

3. No. The shape of the ellipse would be the same, but the ellipse might be bigger or smaller than what is on the friend's picture. To draw the exact same kind of ellipse, you would need to know either the length of the major axis or the distance between the foci.

4. If the eccentricity of the ellipse is 0.9 and the major axis 20 cm, the distance between the foci is 0.9×20 cm = 18 cm.

Student Worksheet 3

Answers from Table 1

Object	Distance between foci *(AU)*	Distance between foci *(model; cm)*
Jupiter	0.51	0.51
Saturn	1.09	1.09
Uranus	1.77	1.77
Neptune	0.66	0.66
Pluto	18.80	18.80
Halley's Comet	34.80	34.80
Pallas *(asteroid)*	1.27	1.27
Ixion *(Kuiper Belt Object)*	18.94	18.94

Questions

1. The orbits of the planets have low eccentricities—they are pretty circular. The exception is Pluto, which has high eccentricity. The orbits are also oriented in different directions from each other. The sizes of the orbits are obviously different, as well.

2. All the orbits in the Solar System are ellipses with the Sun in one focus. Pluto's orbit is similar to Ixion's. The planetary orbits of Jupter, Saturn, Uranus, and Neptune are very different from Comet Halley's, even from the Kuiper Belt Object's and asteroid's—they are much more circular.

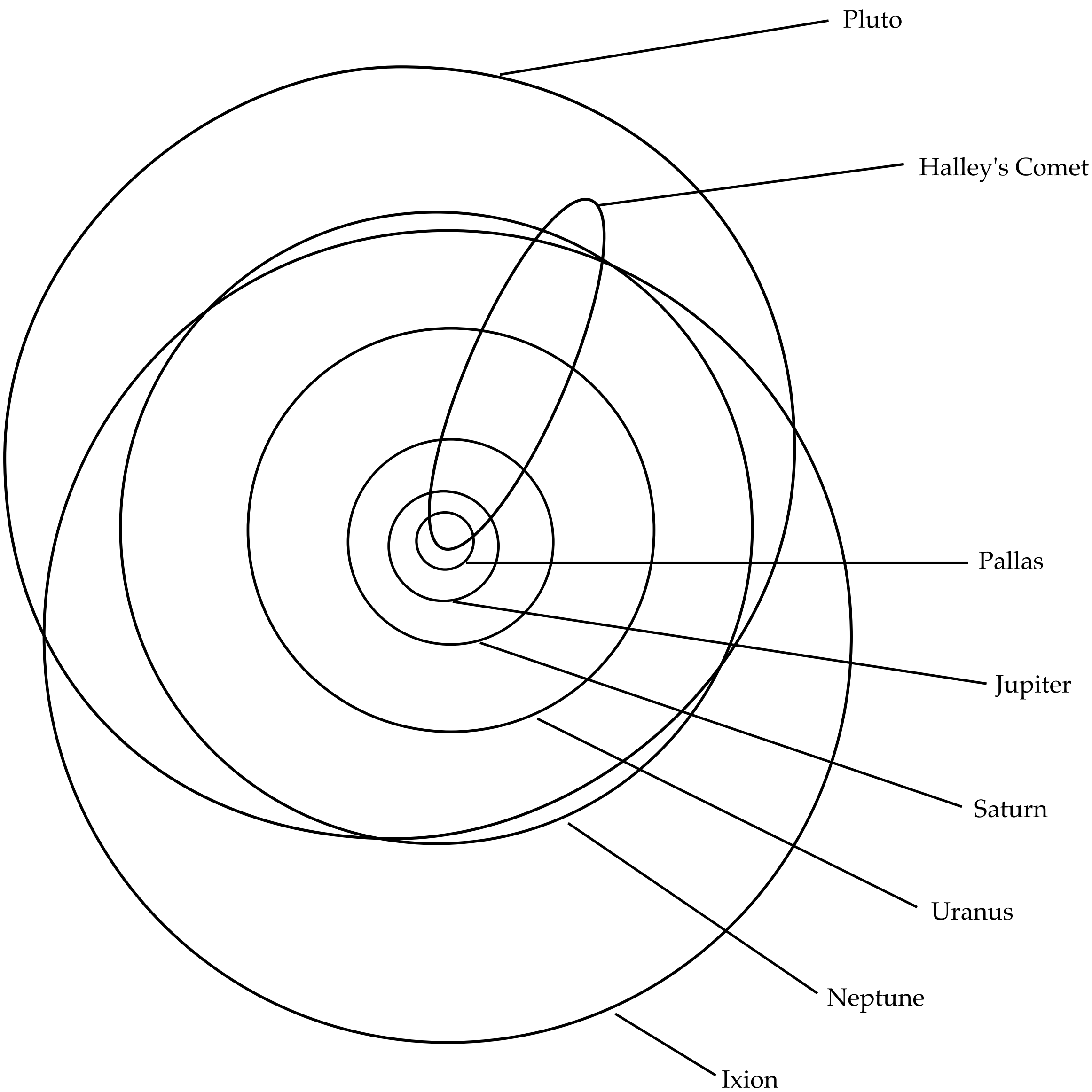
3. The distances between the inner planets are much smaller than those between the outer planets.

4. Answers for Hale-Bopp

Object	Distance between foci *(AU)*	Distance between foci *(model; cm)*
Comet Hale-Bopp	498	498

No, you could not. You would need a much larger paper (in fact, over 10 times as large).

Example of results of Activity 2



Student Worksheet 1:
Ellipses Are Eccentric!

Name ____ Date ___________

Background Information:

An ellipse is a geometrical shape that looks like a squashed circle. It is easy to draw one. Place two fixed points on a piece of paper. Tie a string around each of the fixed points, and draw a curve by pulling the string taut and sweeping it around the paper with a pen or pencil (see Figure S1). The places where the two fixed points are located are called the ellipse's foci (plural of focus). The length of the long axis of the ellipse is called its major axis (see Figure S2). The small axis perpendicular to the major axis is called the minor axis.

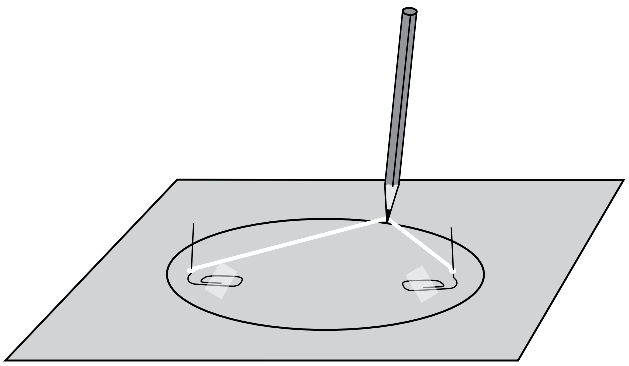


Figure S1. How to draw an ellipse with two paper clips, string, and a pencil.

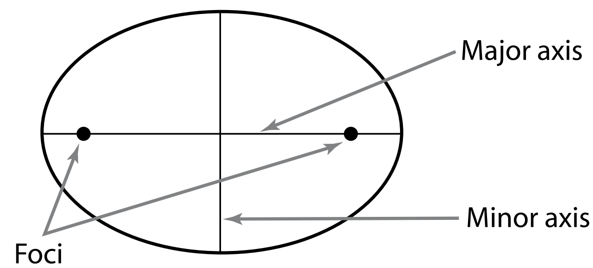


Figure S2. The properties of an ellipse can be described by the location of its foci and the lengths of its major and minor axes.

Materials:

- 2 paper clips
- Transparent tape
- Pen or pencil
- String
- Scissors
- A piece of paper
- Colored pencils

Procedures:

1. Cut a piece of string approximately 25 cm long.

2. Lie two paper clips flat on the table, and bend the end of the wire straight up in the air. Tape the paper clips on the paper about 5 cm apart.

3. Tie each end of the string to one of the paper clips.

4. Pull the string taut with your pen or pencil, and move it from side to side, keeping the string taut, in order to create half of the ellipse (see Figure S1). You will need to put the pen or pencil on the other side of the string in order to create the other half of the ellipse.

5. Put at dot where your paper clips are to mark the location of your foci. Now take one of the paper clips and move it a little further away from the first, so that the distance between the foci is about 12 cm. Repeat Step 4 to draw another ellipse.

6. Untie one end of the string from the paper clip, and re-tie it so that the knot is further up the string—that is, so that the length of the string between the knots is shorter than before. Repeat Step 4 with a different color pencil to draw yet another ellipse.

7. Again mark with your pencil or pen where the foci are located. Experiment making ellipses with different distances between the foci, and different lengths of string. Make sure that at each time the length of the string is a little longer than the distance between the foci—otherwise you cannot draw an ellipse! Once you have made four or five ellipses, each in a different color, answer the questions below.

Questions

1. What happens to the ellipse when the foci get further apart? Closer together?

2. What happens to the ellipse when the length of the string between the knots gets shorter? Longer?

3. Could you make a very elliptical ("squashed") ellipse if you had the foci close together? What would you need?

4. Could you make a very round ellipse if you had the foci far apart? What would you need?

5. Based on your observations, what is the parameter that defines an ellipse? Is it the distance between the foci, the length of string, or some combination of the two? Explain.

Student Worksheet 2:
Exploring Eccentricities

Name ______________________________ Date __________

Background Information:

How stretched out an ellipse is can be measured by a quantity called eccentricity. An ellipse's eccentricity is calculated by dividing the distance between the ellipse's foci by the length of the major axis. If an ellipse has an eccentricity of zero, it is a perfect circle. If an ellipse has an eccentricity close to one, it is very long and narrow.

$$\text{Eccentricity} = \frac{\text{distance between foci}}{\text{length of major axis}}$$

In our case, the length of the major axis is the same as the length of the string used to draw the ellipse.

Transfer of Knowledge

Answer the following questions about ellipses:

1. a. What is an ellipse where the two foci are at the same point?

   b. What is the eccentricity of this kind of ellipse?

2. a. You cannot draw an ellipse where the distance between the foci is exactly the same as the length of the string. But what geometrical shape would you get closer and closer to if you drew ellipses where the two values are closer and closer together?

   b. What would be the eccentricity of this ellipse? Can any real ellipse have this eccentricity?

3. Imagine that you are talking to your friend on the telephone, and she has a picture of an ellipse that she wants you to draw. S/he tells you that the eccentricity is 0.9. If you draw an ellipse with that eccentricity, is it guaranteed to look exactly like the one that your friend has? Why or why not? What else might you need to know in order to draw the exact same ellipse?

4. Draw an ellipse on another piece of paper with an eccentricity of 0.9 and a major axis of 20 cm.
   (*Hint: What is the first thing you need to know in order to set up your ellipse?*)

Student Worksheet 3:
The Eccentricity of Solar System Objects

Name ______________________________ Date ___________

Materials:

- 2 paper clips
- 1 piece of string, at least 375 cm (148 in) in length
- Pen or pencil (Optional: 8 different colors)
- 1 piece of paper approximately 50 cm × 50 cm (20 in × 20 in) poster board size paper works well
- Transparent tape
- Protractor
- Meter stick or a ruler
- Calculator

Background Information:

All objects that go around the Sun travel along paths called orbits. The shapes of all orbits are ellipses of different sizes, eccentricities, and orientations. In all cases, the Sun is located at one of the foci. You will be making a scale model of the Solar System by drawing the orbits of some of the planets and other objects in the Solar System.

Relevant equation: $$Eccentricity = \frac{\text{distance between foci}}{\text{length of major axis}}$$

Procedures:

1. Using Table 1, determine the distance between the foci for each object, based on the eccentricities and sizes of the major axes for the model you will make. Add the results in the appropriate columns in the Table.

2. Tape the paper to your desk or floor so that it covers the surface.

3. Place a dot in the center of the paper to represent the Sun.

4. Using a meter stick, draw a line through the Sun horizontally on your desk. This line will represent the orientation of the Earth's orbit in the Solar System.

5. Create the orbit of Jupiter:
   a. The foci of different orbits are not usually on the same line, so you need to determine the orientation of each of the orbits. To do so for Jupiter, find Jupiter's orientation in Table 1, and measure the angle from Earth's orientation using your protractor. If the angle is positive, measure the angle counter-clockwise above the Earth line; if the angle is negative, measure it clockwise below the Earth line.
   b. Draw a faint guideline from the Sun through this angle. This line represents the orientation of Jupiter's orbit in space, compared to Earth's.
   c. To find the other focus of Jupiter's orbit, find the distance between the foci on Table 1, measure the distance from the Sun focus along Jupiter's line of orientation, and mark the location to the other focus.

d. Take your paper clips and tape them to the two foci, just like you did in Activity 1.
e. Cut the string to the length of 6 cm longer than the distance indicated in the "Major Axis" column in Table 1. Tie each end of the string around the paper clips. Make sure that the length of string between the knots tied to the clips is the same as the length of the "Major Axis." You can tie the knots on the string first to make sure the distance is right and then slide the knots onto the paper clips.
f. Create Jupiter's elliptical orbit in the same manner that you created the ellipses in Activity 1.
g. Remove the paper clips (and the tape), and complete any part of orbit you may not have been able to draw because of the presence of paper clips or tape.

6. Repeat the process for the other objects in Table 1. Label each orbit with the name of the object. You may want to use different colors for the different objects.

Table 1

Object	Eccentricity of orbit	Major axis *(AU)*	Major Axis *(model; cm)*	Distance between foci *(AU)*	Distance between foci *(model; cm)*	Orientation with respect to Earth's orbit *(degrees)*
Jupiter	0.049	10.4	10.4			-88
Saturn	0.057	19.2	19.2			-11
Uranus	0.046	38.4	38.4			68
Neptune	0.011	60.1	60.1			-58
Pluto	0.24	78.5	78.5			121
Halley's Comet	0.97	35.9	35.9			68
Pallas *(asteroid)*	0.23	5.5	5.5			21
Ixion *(Kuiper Belt Object)*	0.24	78.9	78.9			-93

Questions:

1. How are the orbits of the planets similar to one another? How are they different?

2. How are the orbits of the planets similar to the orbits of the other objects? How are they different?

3. You have drawn the orbits of the outer planets; the orbits of the inner planets—Mercury, Venus, Earth, Mars—must fit inside of Jupiter's orbit. What does this tell you about the distances between the inner planets compared to the distances between the outer planets?

4. Halley's Comet is a short-period comet (the time it takes for it to go around the Sun once is 76 years, long from a human perspective, but short for comets.) A recent long-term comet visiting the inner Solar System is Comet Hale-Bopp, which a lot of people on Earth saw in the sky in 1997. It takes Comet Hale-Bopp about 4,000 years to go around the Sun once. Below is the entry for this comet for Table 1. Calculate the distance between the foci and enter them into the table below.

Object	Eccentricity of orbit	Major axis *(AU)*	Major Axis *(model; cm)*	Distance between foci *(AU)*	Distance between foci *(model; cm)*	Orientation with respect to Earth's orbit *(degrees)*
Comet Hale-Bopp	0.995	500	500			-50

Could you draw the orbit of Comet Hale-Bopp in your model?