Voyage: A Journey through our Solar System

Grades 5-8

Lesson 1: Our 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 1: Our Solar System

Lesson at a Glance

Lesson Overview

In this lesson, students tour the Solar System. They examine and define its various components—the Sun, planets, moons, comets, asteroids, and Kuiper Belt Objects. They recognize that the Solar System is the family of the Sun, an average star, and other stars have families of their own. Taking a close look at the planets they find that characteristics like size, location, composition, and presence of rings and moons, reveal two major categories of planets—terrestrial (Earth-like) and Jovian (Jupiter-like). But tiny Pluto seems to be in a class all its own, perhaps the largest of the many icy worlds discovered beyond Neptune.

Lesson Duration

Two to four 45-minute class periods depending on the amount of research and project time allotted in class.

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 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 are the basic components of the Solar System?
- What are the unique characteristics of each planet in the Solar System?

Concepts

Students will learn the following concepts:

- The Solar System has many components, including the Sun, nine planets, their moons, asteroids, comets, and Kuiper Belt Objects.
- The components of the Solar System can be classified based on characteristics such as composition, size, location, etc.
- While each planet is unique, there are a number of characteristics shared across the planetary family.
- The planets fall into two general categories—terrestrial and Jovian—based on their characteristics.

Objectives

Students will be able to do the following:

- Identify and describe the characteristics of different components of our Solar System.
- Organize the family of planets into two categories—terrestrial versus Jovian—and be able to justify this based on shared planetary characteristics.
- Synthesize knowledge of planets and other Solar System components to narrate a spacecraft's voyage through the Solar System.

Science Overview

When the ancient people of Earth studied the night sky, they noticed that five "stars" moved with respect to the others. They called them "planets," from the Greek word for "wanderer," and kept careful records of their motions. These records eventually enabled astronomers to figure out why the "wanderers" moved as they did: the planets, including our Earth, orbit around the Sun. Over the years, telescopes have revealed the existence of three other planets, too faint to have been seen by the ancients, bringing the total number to nine (including Earth).

Scientists now know that the planets are just one component of the Solar System. Besides the Sun and the planets, other significant components in the Solar System include the planets' moons, asteroids, comets and other small icy bodies in the outer reaches of the Solar System. In any exploration of the Universe, it is good to start with the Solar System—Earth's neighborhood.

The Sun

The Sun is a star. The reason it looks so big and bright as compared with the stars in the night sky is that it is very close to the Earth. If the distance from the Sun to Earth (about 150 million km; or about 93 million miles) is scaled to about 15 m (45 ft), the nearest star to the Sun would be located over 4,000 km (2,490 miles) away. That is, if the Sun and the Earth were located in Washington, D.C., the nearest star to the Sun would be in California. Most stars that we see are much further away from the Earth; this is why they look so small in the night sky, even if they are similar to the Sun.

The Sun is at the center of the Solar System. The planets, asteroids and comets all revolve around the Sun. The Sun's role as the center of the planetary system comes 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 brings energy to the rest of the Solar System and largely dictates the temperatures on the planets.

Terrestrial Planets

There are two basic types of planets, Earth-like ("terrestrial") planets and Jupiter-like ("Jovian") planets. The terrestrial planets—Mercury, Venus, Earth and Mars—are small, dense, rocky worlds. They are located in the inner part of the Solar System, they have solid surfaces, just a couple moons at most, rotate slowly, and have no rings around them.

Mercury is the closest planet to the Sun and smallest of the terrestrial planets. It has a very tenuous atmosphere, which is only a little more substantial than a vacuum. Sunlight heats up the surface of the planet to high temperatures during the day, up to 450ºC (840ºF). At night, the surface cools off rapidly, and the temperatures can drop down to -180ºC (-300ºF). This daily temperature variation is the largest of all of the planets. However, Mercury's day is much longer than Earth's. Due to Mercury's closeness to the Sun and its slow rotation, the length of one day on Mercury is equal to 176 Earth days; that is, the time from one sunrise to another on the surface of Mercury is 176 Earth days (while on Earth, this is equal to one day, or 24 hours.)

Venus, a near twin in size to the Earth, has a very thick atmosphere composed of primarily carbon dioxide gas. The thick carbon dioxide atmosphere traps heat from the Sun during the day and does not let the surface cool at night; as a result, temperatures on the Venusian surface are over 464ºC (867º F). The high temperature and unbreathable thick atmosphere would make the planet very inhospitable to human visitors. None of the robotic spacecraft (called Venera) sent to land on the planet's surface by the Soviet Union in the 1970s and 1980s were known to last more than a little over two hours under the harsh Venusian conditions.

Earth is humanity's home planet. Most of its surface (over 70%) is covered with oceans, with the rest featuring a wide variety of land forms, from mountains and valleys to plains and beaches. Earth has a thick atmosphere, which is mostly nitrogen (78%) and oxygen (21%), with other gases such as argon, carbon dioxide, and water present in small amounts. The region on and near the surface of Earth (both above and below ground) is filled with life. The presence of liquid water on the planet's surface and the existence of life make the Earth a unique object in the Solar System. Whether life could and does exist outside of Earth is the subject of study through the science of astrobiology.

Mars is about half the size of Earth in diameter. This makes the surface of Mars equal in area to all the land area on Earth. Mars has a carbon dioxide atmosphere, but it is extremely thin, only about one percent as thick as Earth's atmosphere. The thin air does not retain heat well, and surface temperatures range from a frigid -130ºC (-200ºF) on a cold winter night to 27ºC (80ºF) at the equator on a hot summer day. Mars has polar ice caps, made of water ice and carbon dioxide ice. There may be ice under the surface of Mars at lower latitudes, as well. The Martian surface has features that look like dry streambeds, leading many researchers to surmise that at some time in the distant past, Mars may have had liquid water flowing on its surface.

Our Solar System
Lesson at a Glance
Science Overview
Conducting the Lesson
Resources

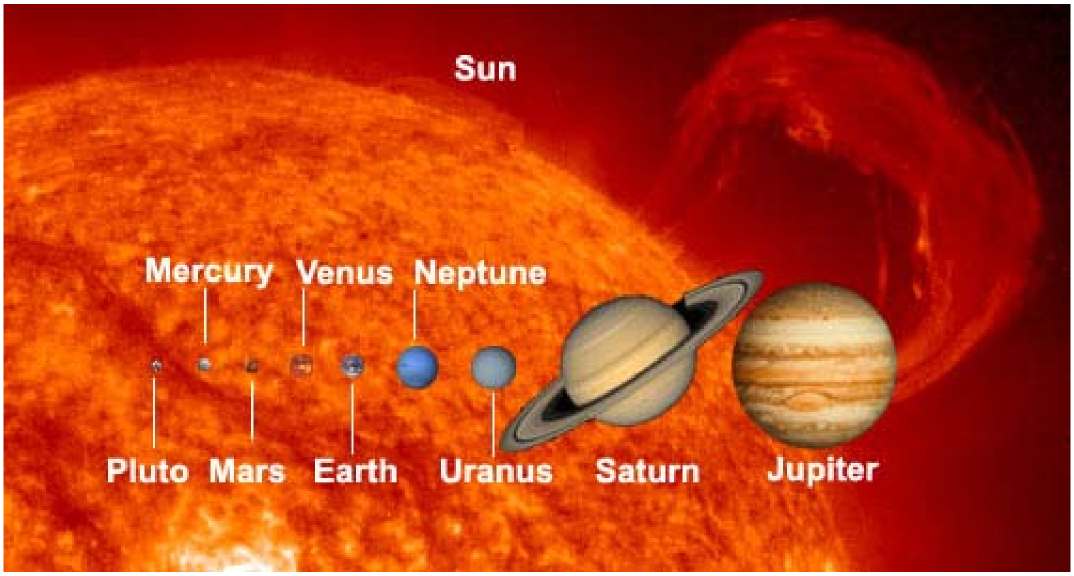

Figure 1: The relative sizes of the nine planets in comparison with the Sun. Note that the planets are listed in order of increasing size, not in order of distance from the Sun. (Picture credit: NASA/JPL; http://spaceplace.jpl.nasa.gov/sse_flipflop2.htm)

Jovian Planets

The Jovian planets—Jupiter, Saturn, Uranus and Neptune—are large planets located in the outer part of the planetary realm of the Solar System. The Jovian planets are gas giants—large objects made mostly of hydrogen and helium. They are much larger than terrestrial planets; for example, eleven Earths could fit across Jupiter's equator. They are rapidly rotating objects: they rotate once around their axis in less than a day while terrestrial planets take anywhere from 24 hours (1 day) to months to rotate once. They all have rings, and extensive families of moons. They have no solid surface on which to stand, and the apparent visible surfaces are just the top layers of clouds in their atmospheres. Deeper in their atmospheres, the gases get thicker and thicker, until finally they turn into a liquid. At their centers, they may have a solid, rocky core a few times the size of Earth.

Jupiter is the largest planet in the Solar System. It is about 318 times as massive as Earth, and over 1,300 Earths could fit inside of it. In fact, if Jupiter was about 75 times as massive as it is, it would have become a star in its own right, and the Solar System would have been a double star system. Like all Jovian planets, Jupiter's surface shows complicated wind patterns. Perhaps the most recognizable feature on Jupiter's surface is the Great Red Spot, a huge storm, twice the diameter of Earth, which has been raging for at least 300 years.

Saturn is just a little smaller than Jupiter (its diameter is about 85% of Jupiter's) but a lot lighter (its mass is about a third of Jupiter's). This means that it has a very low density. In fact, its density is the lowest of all the planets and less than the density of water. This leads to the popular description that in a bathtub filled with water (assuming the tub is big enough to hold a planet) Saturn would float. Still, in composition and internal structure, the planet is thought to be fairly similar to its larger sibling, Jupiter.

Perhaps Saturn's most striking property is its exquisite ring system. All Jovian planets are surrounded by a complex ring system made of icy particles. Saturn's ring system is, by far, the most beautiful—an extensive, complex system of billions of tiny particles orbiting the planet above its equator. The rings of the other Jovian planets are much thinner and fainter. Scientists are still trying to determine the origin of the ring particles; the most commonly accepted suggestion is that they are bits of dust blown off the planets' moons by asteroid or meteoroid impacts.

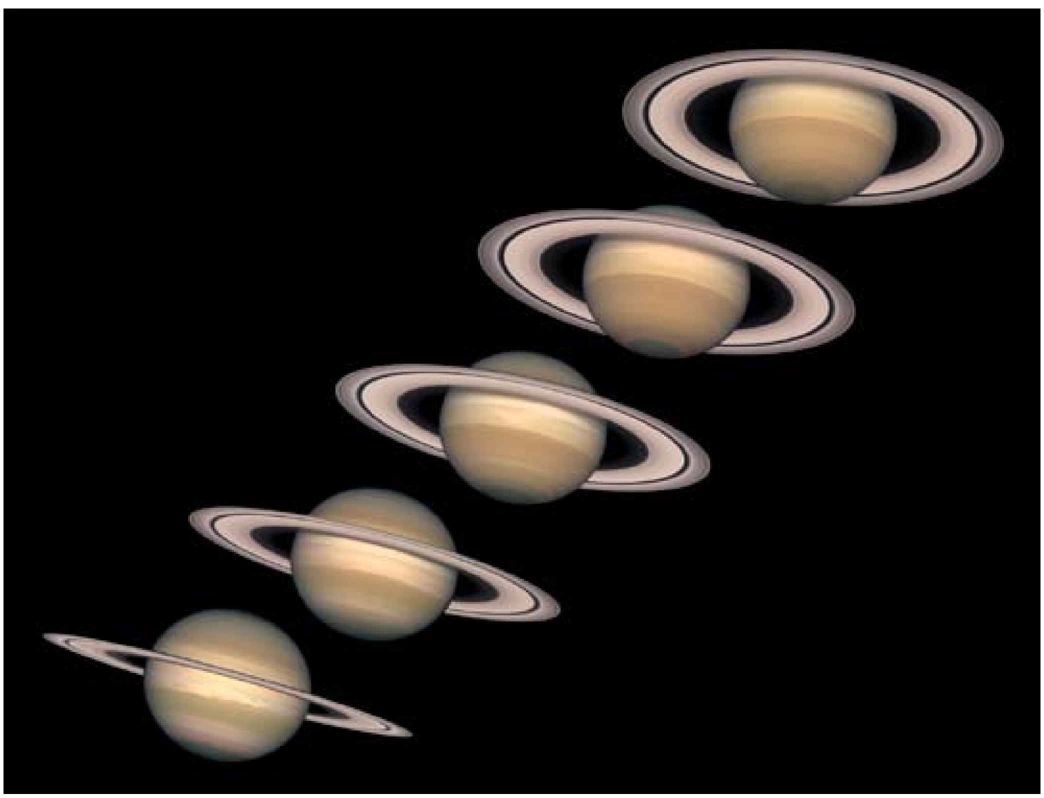

Figure 2: Saturn and its ring system seen from different angles by the Hubble Space Telescope in 1996-2000. Picture credit: NASA/JPL Planetary Photojournal; http://photojournal.jpl.nasa.gov/jpeg/PIA03156.jpg)

Uranus's unique feature is that it appears to have been knocked over sometime in the past. Most planets orbit around the Sun spinning upright; that is, their rotational axes are almost perpendicular with respect to their orbit (with small deviations, like the Earth's 23.5° tilt). Uranus's rotation axis, however, is almost lying within its orbital plane. The cause of this unique feature is not certain, but it has been suggested that it was caused by an impact of a large object, such as a large asteroid or moon. Giant impacts like this were common during the early history of the Solar System; a similar impact is thought to have created the Earth's Moon.

Neptune is similar in size to Uranus (and both are smaller than Jupiter and Saturn). Giant storm centers can be seen on its visible surface, similar to those on the other Jovian planets. The atmosphere features great wind patterns; its winds are the fastest in the Solar System, reaching speeds of 2,000 km/hour (or 1,200 miles/hour). When the Voyager 2 spacecraft (the only spacecraft to visit this remote planet) flew by in 1989, one of the most distinguishing features of the planet was the Great Dark Spot, a storm similar to Jupiter's Great Red Spot (but only about half its size). Later observations of the planet made with the Hubble Space Telescope showed the Spot to have disappeared (or masked by other atmospheric phenomena), and follow-up observations revealed the appearance of another dark spot elsewhere. All these features indicate that Neptune has a very active and rapidly changing atmosphere.

Pluto and Kuiper Belt Objects

Pluto is the smallest planet and has the largest average distance from the Sun. It does not really fit into either the terrestrial or Jovian categories of planets. Like a terrestrial planet, it is small, but, because it is a mixture of rock and ice, its density is low. It most certainly is not a gas giant, but it is located in the outer part of the planetary realm of the Solar System. Since 1992, astronomers have found many objects similar to Pluto beyond Neptune's orbit—they are all small icy worlds most commonly called Kuiper Belt Objects, after the Dutch astronomer Gerard Kuiper (1905-1973). They are sometimes also called trans-Neptunian objects, because they reside in space beyond the orbit of Neptune. Some scientists have suggested that Pluto may be just the largest of these objects, and may not be a planet at all. However, because of its historical association as one of the planets in the Solar System, it is unlikely that Pluto will be demoted from the ranks of the planets anytime soon. In fact, the 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. So, for the time being, and most likely for decades (at least) to come, Pluto is the ninth planet in the Solar System. 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).

Moons

All planets, except for Mercury and Venus, have moons. Like the planets themselves, the moons are very unique objects. Our moon—the Moon—is similar to the terrestrial planets in composition and structure. Its diameter is about one-fourth of the diameter of the Earth. It has no atmosphere and its surface is heavily cratered by meteoroid impacts, like the surface of Mercury. The Moon is thought to have formed when a Mars-sized object smashed into the forming Earth billions of years ago. Material was blasted into orbit around Earth by this collision, and later pulled together by gravity to become the Moon. The Moon is the only celestial body to have been visited by humans (instead of just by robotic spacecraft).

Mars has two moons, Phobos and Deimos. They are small objects that probably were captured by Mars at some point in the past, though it is not certain exactly how it happened.

The Jovian planets have large families of moons; the largest of the moons have been known for decades or even for centuries. Italian astronomer Galileo Galilei (1564-1642) discovered the four largest moons of Jupiter in 1610. These moons—Io, Europa, Ganymede, and Callisto—are now called the Galilean moons in honor of their discoverer. The Galilean moons are all unique. Io is the most volcanic body in the Solar System, with the volcanic activity powered by Jupiter's strong gravitational forces. Europa is covered by ice, and underneath may be a global liquid water ocean. Ganymede is the largest moon in the Solar System. In fact, it is larger than the planet Mercury. Callisto is a little smaller than Ganymede. Both Ganymede and Callisto are covered with craters.

Saturn's moon Titan, the second largest moon in the Solar System, is the only moon that has a significant atmosphere. In fact, its atmosphere is of great interest to scientists, because it is thought to have compounds similar to those in Earth's early atmosphere, before the emergence of life changed the atmosphere on Earth.

Neptune's moon Triton also has an atmosphere, but it is much thinner than Titan's atmosphere. Triton orbits Neptune in a direction opposite to the planet's rotation—this suggests that Triton did not form near the planet (according to how moons are thought to form around planets, the moon would then orbit in the same direction as the planet rotates). Instead, it may have formed elsewhere and was captured by Neptune's gravity at some point in the past.

The Jovian planets have many smaller moons, many of which have been discovered only recently, and there are probably many moons yet to be discovered. Therefore, the total number of moons of the giant planets is just the number of moons discovered to date. In September 2005, Jupiter was known to have 63 moons; Saturn, 47; Uranus, 27; and Neptune, 13.

Even the smallest planet in the Solar System, Pluto, has a moon, Charon. It is about half the size of Pluto and is thought to be composed of a mixture of rock and ice, just like Pluto. Not much is known of Charon, because no spacecraft has ever visited the Pluto system.

Comets

The outer regions of the Solar System are home to the comets: dirty ice balls composed of ices (water ice, as well as other kinds of ices, such as carbon dioxide, ammonia, and methane ices), rock, and dust. They are thought to be remnants of or the actual building blocks of the outer planets, and, therefore, are a subject of great interest for researchers interested in understanding the early history of the Solar System. Comets spend most of their time in the outer reaches of the Solar System and are therefore invisible to observers on Earth. At this point, the comet consists of only its solid body, the nucleus, which is only a few kilometers across and darker than charcoal. It is only when a comet's orbit takes it to the inner parts of the Solar System that a comet becomes observable. The Sun heats the frozen body of the comet, and causes ices on the comet's surface to sublimate—change directly from solid to gas. The resulting gases blown off the nucleus, as well as specks of dust caught in the outflow, form a large cloud of gas and dust particles around the nucleus, called the coma. Comet's coma can be over 1.6 million km (1 million miles) in size. Sunlight pushes against the dust particles in the coma, while the solar wind—fast outflow of electrically charged particles from the Sun—interacts with the gas. As a result, material in the coma is pushed away from the nucleus, forming the third component of the comet, its tail. It is not unusual for the tails of comets to extend tens of millions of km (tens of millions of miles). If comets venture close to Earth, they can be some of the most striking objects in the sky. In ancient times, people often thought their appearance in the sky was an ominous sign.

There are two types of comets. The orbital period of "short-period comets" around the Sun is less than 200 years. They are thought to come from the Kuiper Belt, the region of the Solar System where the icy worlds called Kuiper Belt Objects reside. The second type of comets has orbital periods of more than 200 years. These are long-period comets that are thought to come from a region in the outermost parts of the Solar System called the Oort Cloud (named after the Dutch astronomer Jan Oort, 1900-1992). A gravitational disturbance from outside the Solar System (such as a passing star in interstellar space) is thought

Figure 3: Picture of Comet Halley as taken March 8, 1986. Picture credit: W. Liller; NASA/NSSDC Photo Gallery; http://nssdc.gsfc.nasa.gov/image/planetary/comet/lspn_comet_halley1.jpg)

to occasionally nudge inhabitants of the Oort Cloud and change their orbits around the Sun so that they begin to visit the inner Solar System and become observable comets. Because the Oort Cloud objects are thought to reside in space hundreds or thousands times as far from the Sun as Earth, the existence of the Oort cloud is yet to be conclusively confirmed with astronomical observations.

Asteroids

Asteroids are small rocky objects in the Solar System. They orbit the Sun like planets, but they are a lot smaller. The largest asteroid, Ceres, is a little over 900 km in diameter, and it contains over a third of the mass of all asteroids (which combined is less than the mass of the Moon). There are hundreds of thousands of known asteroids. Astronomers probably have seen almost all of the asteroids larger than 100 km, and about half of those with diameters in the 10-100 km range. But there are probably

Figure 4: Asteroid Gaspra, as shown in the computer-generated picture based on data gathered by the Galileo spacecraft in 1991. (Picture credit: NASA/NSSDC Photo Gallery; http://nssdc.gsfc.nasa.gov/image/planetary/asteroid/gaspra.jpg)

millions of asteroids with sizes in the 1 km range that have never been seen. Most of the asteroids orbit the Sun in the Asteroid Belt, a region between the orbits of Mars and Jupiter. Some of the moons (such as Mars's moons and the outer moons of Jupiter and Saturn) are similar to asteroids, and may actually be captured asteroids rather than having formed in the same way around the planet as the other moons.

Meteors and Meteorites

Sometimes asteroids collide with each other and pieces of them break off. These pieces of broken-off rock (sometimes called meteoroids) travel around the Solar System, and on occasion they may cross paths with Earth and hit the planet. When they fly through the Earth's atmosphere, they can be seen as meteors in the sky as the rocks burn up because of the heating by the atmosphere. These meteors are often called "shooting stars," but they clearly are not real stars. If the rock is sufficiently large, part of it may survive the flight through the atmosphere and fall to the ground. These pieces are then called meteorites. Most of the meteorites come from asteroids, but some are thought to have come from the Moon or Mars, blasted off from their surface by big meteoroid impacts.

Comets leave trails of debris in their wake as they travel through the inner part of the Solar System. When Earth passes through these trails of dust and ice on its orbit around the Sun, the particles hit the Earth and burn up in the atmosphere—these events can be observed from the surface of Earth as meteor showers.

The Origin of the Solar System

Many scientists are investigating the formation of the Solar System. Data from the study of primitive Solar System objects (such as meteorites), examination of the properties of planets, and observations of other planetary systems being formed elsewhere in the Universe have provided a general picture of how the Solar System probably was formed. However, many of the processes are still not completely understood, and a lot more research will need to be performed before a complete picture of the origin of the Solar System is available. What follows is the generally accepted theory of the formation of the Solar System, with many of the details requiring further work and confirmation.

The Solar System was formed about 4.6 billion years ago, when a giant cloud of interstellar gas and dust started to contract under its own gravity. In the central part of the cloud, a precursor of the Sun called a protosun was formed, and around it, a rapidly spinning disk was formed. The disk fed material onto the growing protosun, while at the same time, small grains of dust within the disk collided, stuck together, and grew. Eventually the dust grains became large chunks, which collided and merged together, until planet-sized objects existed within the disk. The planet-sized objects then "swept up" remaining material, pulling leftover gas and dust toward them, and continued to grow. At the same time, the temperature inside the protosun rose, and eventually the temperature became so high that nuclear fusion, the power process of the stars, began. At this point, the Sun became a young star. The energetic, young Sun blew away remnant gas from the disk around it, revealing the Sun's family of planets. Asteroids, comets, and other similar objects in the Solar System are thought to be material left over from building the planets—material that did not quite make it to become a planet, or a major moon around a planet.

This scenario for the formation of the Solar System explains observed similarities between the planets. All the planets revolve around the Sun in the same direction (counterclockwise, as seen from above the north pole of the Sun), and most of them rotate on their axis in a counterclockwise direction. In addition, all the planets circle the Sun in nearly the same plane. All this can be explained because the planets formed out of the same rotating disk. The direction of rotation of the three exceptions (Venus, Uranus and Pluto) may have been caused by a collision with a large object, for example.

The scenario can also explain the differences between the planets, primarily why the terrestrial planets are small and rocky, while the Jovian ones are gas giants. In the inner part of the Solar System, the Sun made it too hot for much of the gas in the disk to condense into solid grains. Only small amounts of high-density materials like rock and metals could be pulled together by gravity to form the small, rocky planets. Farther out in the disk, large planetary embryos were able to pull vast amounts of gases like hydrogen and helium toward them, providing the extensive gaseous atmospheres in these planets.

Other Planetary Systems

According to the theory of star formation, planets should form as natural byproducts during the birth of stars. The first planet around a solar-type star was discovered in 1995, and by September 2005, over 160 planets ("extrasolar planets") had been discovered around nearby solar-type stars. The detection methods are most sensitive to finding large planets close to the stars; therefore, almost all planets discovered to date have been gas giants like Jupiter and Saturn. Most of the systems have also been very different from our Solar System, with the gas giants close to the central star. In the future, improved observational methods may be able to detect Earth-sized planets around other stars, and discover true Solar System analogs (planetary systems with rocky planets near the star and gas giants further out). But even now, the observations have confirmed the theoretical expectation that planetary systems around stars are quite common.

Properties of Planets in the Solar System

Table 1 includes information on some of the basic properties of the planets in the Solar System. Because of the large sizes of and distances between the planets, astronomers prefer not to use kilometers and kilograms or miles and pounds to describe the planets. Instead, they define new units to be used in the study of the Solar System, so that the numbers are easier to use and compare with one another. Distances are measured in Astronomical Units, 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

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
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	88 days	225 days	365.3 days	687 days	11.86 years	29.46 years	84.01 years	164.79 years	247.68 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	47	27	13	1
Rotation Period	59 days	244 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 days 9 hours 18 min retrograde*

Numbers in the table are valid as of September 2005.

*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.

NOTES:

Conducting the Lesson

Warm-Up & Pre-Assessment

Preparation & Procedures

1. Ask students to brainstorm a list of all the components in the Solar System. You can use the table below to guide students to a deeper understanding of the components based on their answers. Through this informal conversation, you should be able to assess students' prior understanding.

2. As a class, use the list of components you just created to develop a definition of the Solar System. *(Desired answer: The Solar System is composed of a star—the Sun—at its center with planets, comets, asteroids, and Kuiper Belt Objects orbiting around it, and moons orbiting their parent planets)* Note – do not discuss the existence of other solar systems beyond our own. Students are to demonstrate their ability to hypothesize this in the *Transfer of Knowledge* section at the end of Activity 1.

Possible Student Answer	Leading Question
Earth	What is the Earth an example of? *(Desired answer: a planet)* What are some other planets? *(Desired answer: Mercury, Venus, Mars, Jupiter, Saturn, Neptune, Uranus, Pluto)*
Sun	What is the Sun? *(Desired answer: it is a star)* But the Sun looks different than other stars. How does it look different? (*Desired answer: it appears bigger and brighter)* Why does it appear bigger and brighter? (*Desired answer: it is an average size star and just appears bigger because it is so close)* Here's a trick question, how many stars are in our Solar System? *(Desired answer: only one—the Sun. The Solar System is the family of the Sun, and gravity keeps the family together.)*
The Moon	Is our Moon the only moon in the Solar System? *(Desired answer: no, many other planets have several moons—Jupiter has 63)* Can you name any other moons? *(Desired answer: Io, Titan, Europa, etc.)*
Asteroid	What is an asteroid made of? *(Desired answer: it is a chunk of irregularly shaped rock or metal)* Where are most of the asteroids in our Solar System? *(Desired answer: between Mars and Jupiter)*
Meteorite	What is the difference between a meteor, meteorite, and a meteoroid? Which one is in space? *(Desired answer: a meteoroid is a chunk of metal or rock that orbits around the Sun and is smaller than an asteroid and has the potential to collide with other bodies, including Earth. A meteorite is a meteoroid that has landed on the Earth. When meteoroids fly through Earth's atmosphere, they can be seen as meteors—streaks of light in the sky.)*
Shooting Stars	Are shooting stars real stars? (*Desired answer: no, shooting stars are not actual objects. They are meteors—streaks of light in the sky caused by pieces of rock and ice burning up in Earth's atmosphere.)*
Comets	What are comets made of? (*Desired answer: rock and ice)* What do comets look like? (*Desired answer: a fuzzy sphere with a tail)*
Galaxies, Black Holes, Neutron Stars, other stars, and other astronomical objects that do not belong to the Solar System.	These objects are not in the Solar System.
Gas and dust	Gas and dust are in the Solar System, however they make up such a small percentage of total mass in the Solar System that they will not be addressed in this lesson.

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Resources

Activity 1: Solar System Catalog

Students will create a catalog for the components in the Solar System. Through their research and class discussion, students will come up with a class-wide definition of each component.

Student Materials (per student)

- Student Worksheet 1
- Scissors
- Pencils
- Lined paper
- Crayons or markers
- Research materials (see suggestions in the *Internet Resources & References* section)
- Construction paper
- Glue or tape

Preparation & Procedures

1. Collect various research materials for students to use. Books, magazine articles, and Internet sites are all possible resources. See the *Internet Resources & References* section for ideas.

2. Collect various arts and crafts materials for students to use in creating their catalogs.

3. Discuss with students how one possible way to learn about the Solar System is to create an inventory of it. You can use the following facilitation to guide students to this conclusion:

   Ask students, if you wanted to know the inventory of a company like Sears, what would you do? *(Desired answer: look through a catalog)* Ask students, what kind of things can you learn about objects in a catalog? *(Desired answer: object name, description, picture, etc.)* Similarly, if you wanted to know the inventory of the Solar System, what would you do? *(Desired answer: also look through a catalog)* Tell students that a catalog of the Solar System does not exist. Ask them what they should do. *(Desired answer: make a catalog)* Tell students that is exactly what they are going to do.

4. Distribute Student Worksheet 1 and read the directions aloud as a class. This activity can be done individually or in small cooperative groups. Provide students with adequate time for researching the components in the Solar System and creating their catalog.

Teaching Tip

If class time is limited, you can assign the catalog as a homework assignment or short-term project.

Reflection & Discussion

1. Have students share their catalogs with their classmates. As a class, discuss how each student or group described each component. Ask students if each component was always described in the same way. *(Desired answer: no, although the descriptions for a component were similar, there was variation among the class)*

2. After each student or group has shared their descriptions, develop a class definition for each component.

Sample Answers:

Sun – the central body in the Solar System of great mass and size, almost entirely composed of hydrogen and helium. The Sun produces its own energy (by means of nuclear fusion reactions at its core); this energy makes it's way to the Sun's surface which blazes brightly. The Sun's light bathes the Solar System, and the energy contained in its light powers weather on the planets.

Planet – a large body that revolves around the Sun

Moon – a natural object that orbits a planet

Comet – a celestial body that has a solid 'nucleus' of ice and rock, that usually has a less circular (or more elliptical) orbit around the Sun than do the planets, and that, when in the part of its orbit near the Sun, develops a gaseous head (coma) and long tail which points away from the Sun

Asteroid – a small celestial body orbiting the Sun, commonly found especially between the orbits of Mars and Jupiter

Meteoroid – a small piece of rock orbiting the Sun; smaller than an asteroid

Kuiper Belt Objects – icy worlds orbiting the Sun beyond the orbit of Neptune in a region of the Solar System called the Kuiper Belt

Lesson Adaptations

Talented and Gifted: Have students assign a price value to each Solar System component. Students must justify the price of each component. For example, is the price based on size, importance, or abundance?

Assessment Criteria for Activity 1

5 Points

- Each page in the catalog contains all of the required information.
- All facts in the catalog are accurate.
- The catalog has very attractive formatting and well organized information.
- The pictures go very well with the text.
- Student accurately answered the *Transfer of Knowledge* question and thoroughly supported their opinion.

4 Points

- Each page in the catalog contains most of the required information.
- Most facts in the catalog are accurate.
- The catalog has attractive formatting and well organized information.
- The pictures go well with the text.
- Student accurately answered the *Transfer of Knowledge* question and supported their opinion.

3 Points

- Each page in the catalog contains some of the required information.
- Some facts in the catalog are accurate.
- The catalog has well organized information.
- The pictures are related to the text.
- Student accurately answered the *Transfer of Knowledge* question and attempted to support their opinion.

2 Points

- Each page in the catalog contains a few pieces of the required information.
- A few facts in the catalog are accurate.
- The catalog has organized information.
- The pictures are related to the text, but there are too few of them.
- Student incorrectly answered the *Transfer of Knowledge* question but support their opinion.

1 Point

- Each page in the catalog contained at least one piece of the required information.
- Few facts in the catalog are accurate.
- The catalog's formatting and organization is confusing to the reader.
- No pictures were included.
- Student incorrectly answered the *Transfer of Knowledge* question and did not support their opinion.

0 Points

- No work was completed.

Our Solar System
Lesson at a Glance
Science Overview
Conducting the Lesson
Warm Up & Pre-Assessment
Activity 1: Solar System Catalog
Activity 2: What a Wonderful World
Lesson Wrap-Up
Resources

Transfer of Knowledge

Have students apply what they have learned in order to answer the following question located on Student Worksheet 1:

> Is our Solar System the only planetary system, or one of many? Support your answer with information from your research and the class discussion.
>
> *Sample Answer: Our star the Sun has a family of planets we call the Solar System. But our star is just an average star so it can be assumed that other stars also have families of objects orbiting around them, meaning that they have their own solar system. A planetary system in general consists of a star at its center with a family of objects, such as planets, asteroids, and comets, orbiting around it.*

Extensions

- Students can use their research information to create a Power Point version of their catalog.

- Students can research whether other solar systems are known to exist. (By September 2005, over 160 planets have been discovered orbiting other solar-type stars.)

Placing the Activity Within the Lesson

In Activity 1, students researched and defined each component in the Solar System. Students learned that the Sun, just an average star, is at the center of the Solar System. Remind students that just as Earth is one planet in the family of planets called the Solar System, the Sun is just one star in a larger family of stars. And that a great number of these stars have their own solar systems. Ask students if they know what a large collection of stars is called. *(Desired answer: a galaxy)* Ask students if they know the name of our Galaxy. *(Desired answer: the Milky Way)* Ask students what we have when all of the galaxies and all of the material between the galaxies are combined. *(Desired answer: the Universe)*

Bringing the students back to our Solar System, ask them if they think that the objects within a component of the Solar System are all identical or if there is variation. *(Desired answer: regardless of component— planets, moons, asteroids, comets, Kuiper Belt Objects—there is a great deal of variation across the objects in that component)*

In Activity 2, students will explore the similarities and differences between the planets.

Notes on Activity 1:

Our Solar System

Lesson at a Glance

Science Overview

Conducting the Lesson

Warm Up & Pre-Assessment

Activity 1: Solar System Catalog

Activity 2: What a Wonderful World

Lesson Wrap-Up

Resources

Activity 2: What a Wonderful World

Students will research one planet in depth. Students will use their research to create a travel brochure for that planet.

Teacher Materials

- 9 sheets of large paper
- Marker

Student Materials (per student)

- Student Worksheet 2
- Student Worksheet 3
- Scissors
- Pencils
- Crayons or markers
- Research materials (see suggestions in the *Internet Resources & References* section)
- Construction paper
- Glue or tape
- 11″ x 17″ piece of paper

Preparation & Procedures

1. Collect various research materials for students to use. Books, magazine articles, and Internet sites are all possible resources. See the *Internet Resource & References* section for ideas.

2. This project can be done individually or within groups. Students may choose their own planet or you can assign a particular planet. Make sure all planets have been chosen.

3. Collect various arts and crafts supplies, along with 11″ x 17″ pieces of paper.

4. Ask students: if they wanted to learn more about an exotic or unusual destination for a vacation, who could they speak to? (*Desired answer: a travel agent)* What materials do travel agents have that could help you learn more without ever leaving your hometown? (*Desired answer: travel brochures)* Ask students what other travel destinations may be possible in the future. (*Desired answer: the Moon or*

> **Teaching Tip**
>
> If class time is limited, you can assign the travel brochure as a homework assignment or short-term project.

planets) Ask students if travel brochures exist for those locations. *(Desired answer: no)* Ask students what they could do? *(Desired answer: make them)* Tell students that is exactly what they are going to do.

5. Distribute Student Worksheet 2 and read the directions aloud as a class. Provide students with adequate time for researching their planet and creating their travel brochure.

6. Have students prepare a short presentation to the class to share what they have learned. Have students present the planets in the order they are located from the Sun, starting with Mercury. As students present, create a list of characteristics for each planet on a large sheet of paper and hang them around the room, keeping them in order according to their distance from the Sun.

Reflection & Discussion

Through their research and class discussion, students should have learned that each planet is a unique world, yet similarities do exist between them. Examine the characteristics listed on the large pieces of paper you have created. Discuss the following themes that emerge:

- Some planets have a rocky composition and some planets have a gaseous composition.
- Some planets are located between the Sun and the Asteroid Belt and some planets are located beyond the Asteroid Belt.
- Some planets are larger than the Earth and some planets are smaller.
- Some planets have rings and some planets do not.
- Some planets have many moons and some planets have few or no moons (2 or less).
- Some planets' days (rotational period) are less than 18 hours and some are greater.

Students should learn that common themes exist among the planets, and that groups of planets share many common characteristics that we can use to group or classify the planets.

Transfer of Knowledge

In order for students to apply what they have learned, ask them to complete Student Worksheet 3. Students will organize the themes above using Venn diagrams, and conclude from these diagrams that there are two general categories of planets—terrestrial (earth-like) and Jovian (Jupiter-like). See the *Teacher Answer Key* for Student Worksheet 3.

Assessment Criteria for Activity 2

5 Points

- Each section in the brochure contains all of the required information.
- All facts in the brochure are accurate.
- The brochure has very attractive formatting and well organized information.
- The pictures go very well with the text.
- Students accurately placed all of the planets in the Venn diagrams located on Students Worksheet 3.
- Student accurately classified the planets and thoroughly supported their answer.

4 Points

- Each section in the brochure contains most of the required information.
- Most facts in the brochure are accurate.
- The brochure has attractive formatting and well organized information.
- The pictures go well with the text.
- Students accurately placed most of the planets in the Venn diagrams located on Students Worksheet 3.
- Student accurately classified the planets and supported their answer.

3 Points

- Each section in the brochure contains some of the required information.
- Some facts in the brochure are accurate.
- The brochure has well organized information.
- The pictures are related to the text.
- Students accurately placed most of the planets in the Venn diagrams located on Students Worksheet 3.
- Student accurately classified the planets and attempted to support their answer.

2 Points

- Each section in the brochure contains a few pieces of the required information.
- A few facts in the brochure are accurate.
- The brochure has organized information.
- The pictures are related to the text, but there are too few of them.
- Students accurately placed a few of the planets in the Venn diagrams located on Students Worksheet 3.
- Student incorrectly classified the planets but supported their answer.

1 Point

- Each section in the brochure contained at least one piece of the required information.
- Few facts in the brochure are accurate.
- The brochures formatting and organization is confusing to the reader.
- No pictures were included.
- Students accurately placed hardly any of the planets in the Venn diagrams located on Students Worksheet 3.
- Student incorrectly classified the planets and did not support their answer.

0 Points

- No work was completed.

Extensions

- Students can create a travel brochure for the other objects in the Solar System, such as moons or comets.
- Students can combine all of their brochures to make a reference book on the planets for the class.
- Students can create a 3-D model of their planet to display its surface characteristics.

Placing the Activity Within the Lesson

Have a class discussion about the placement of the planets on the Venn diagrams, and the two categories—terrestrial and Jovian—in which most of the planets seem to fall. Discuss with students how Pluto does not seem to fit in with the rest of the planets. Ask students if Pluto seems to fit better with another Solar System component. *(Desired answer: Kuiper Belt Objects, which are small icy worlds beyond Neptune. In fact, Pluto may simply be the largest one, and really not a planet at all. However, for historical reasons, Pluto is classified as a planet and will remain so for the forseeable future)*

Notes on Activity 2:

Lesson Wrap-Up

Transfer of Knowledge for the Lesson

In order to explore celestial objects, humans build spacecrafts to travel through the Solar System. Have students write a short story from the point of view of a spacecraft traveling through the Solar System, starting at the Sun. What would you see? Have students describe and illustrate the Sun and each of the planets, as well as other components of the Solar System such as moons, comets, asteroid and Kuiper Belt Objects, as they pass by. Students should describe each object or component in the correct order from the Sun and use information from their research and the class discussions to describe how each object would look.

Assessment Criteria for the Lesson

5 Points
- The entire story is related to the Solar System and is informative to the reader.
- All facts presented in the story are accurate.
- Illustrations are detailed, creative, and relate to the text on the page.
- The story is well organized and neat. One idea flows into the other and the final draft is clean and easily readable.

4 Points
- Most of the story is related to the Solar System and is informative to the reader.
- Almost all of the facts presented in the story are accurate.
- Most illustrations are detailed, creative, and relate to the text on the page.
- The story is pretty well organized and neat. One idea flows into the other and the final draft is readable.

3 Points
- Some of the story is related to the Solar System and is informative to the reader.
- Some of the facts presented in the story are accurate.
- Some illustrations are detailed, creative, and relate to the text on the page.
- The story is organized and neat. The reader can follow the story and the final draft is readable.

2 Points
- Some of the story is related to the Solar System and is informative to the reader.
- A few of the facts presented in the story are accurate.
- Some illustrations are detailed, creative, and relate to the text on the page.
- The story is organized and neat. One idea flows into the other and the final draft is readable.

1 Point
- Little of the story is related to the Solar System and is informative to the reader.
- A few of the facts presented in the story are accurate.
- At least one of the illustrations is detailed, creative, and relate to the text on the page.
- The story is poorly organized and not neat. The story is confusing to the reader and the final draft is not readable.

0 Points
- No work was completed.

Lesson Closure

Throughout the lesson, students learned about the various components of the Solar System and took an in depth look at the planets. Students synthesized that information to develop a mental model of the Solar System that they conveyed in the short story they created for the *Transfer of Knowledge for the Lesson*. Discuss with students how they could take their mental model to the next level by creating a physical model of the Solar System. Ask students what other information they might need. (*Desired answer: the distances between the planets and a space to set up the model)*

Extensions for the Lesson

Have students create a scale model of the Solar System by completing the Voyage lesson entitled *Voyage of Discovery: Building a Scale Model Solar System*.

Resources

Internet Resources & References

Student-Friendly Web Sites:

Astro for Kids
www.astronomy.com/asy/default.aspx?c=a&id=1091/

Kids Astronomy
www.kidsastronomy.com

NASA Kids
kids.msfc.nasa.gov

Star Child
http://starchild.gsfc.nasa.gov

Welcome to Astronomy for Kids!
http://www.dustbunny.com/afk/

Teacher-Oriented Web Sites:

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

The Busy Teacher's Web site
www.ceismc.gatech.edu/busyt/astro.html

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

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

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

The Nine Planets
www.nineplanets.org

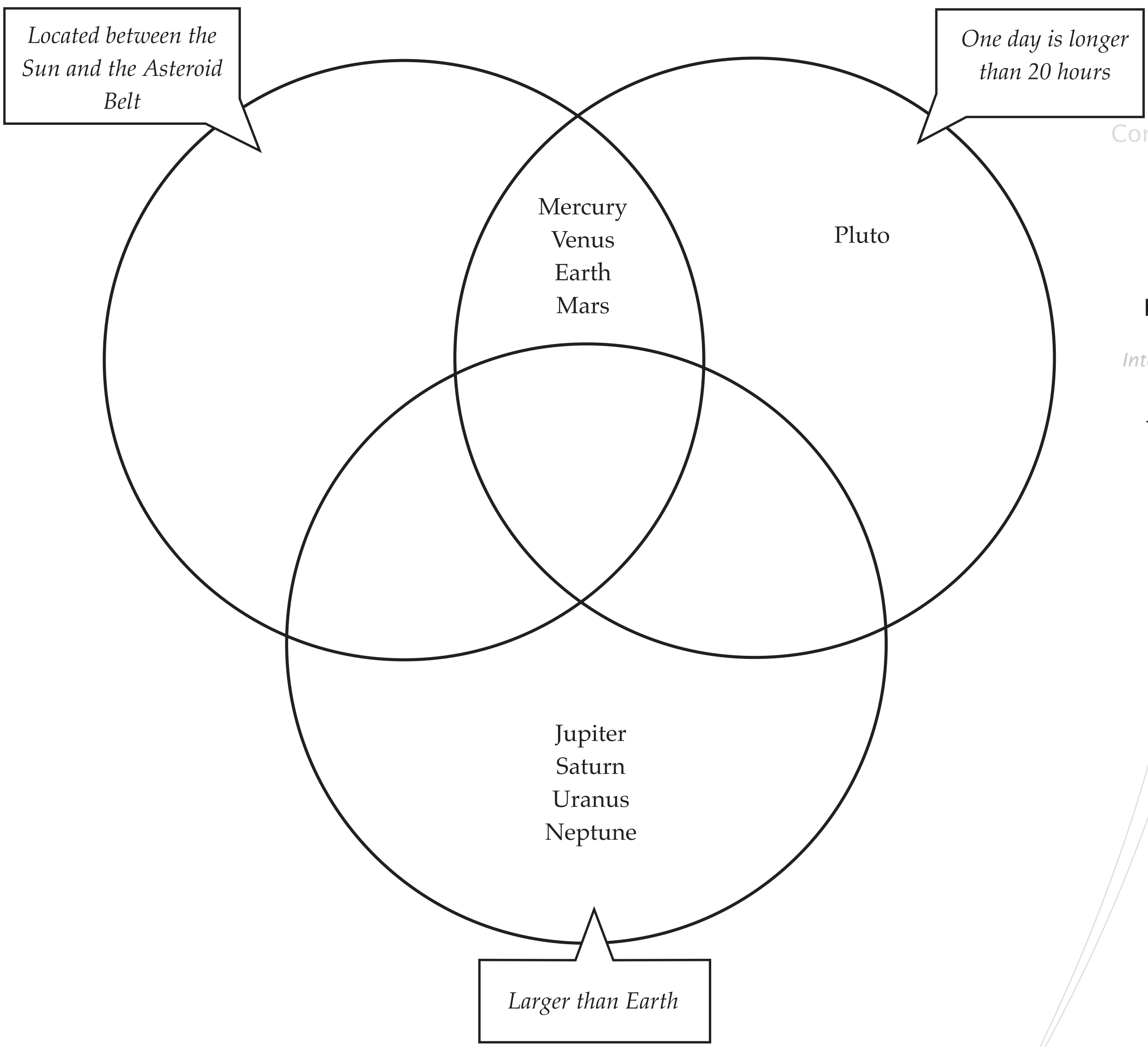
Pro-Teacher
www.proteacher.com/110066.shtml

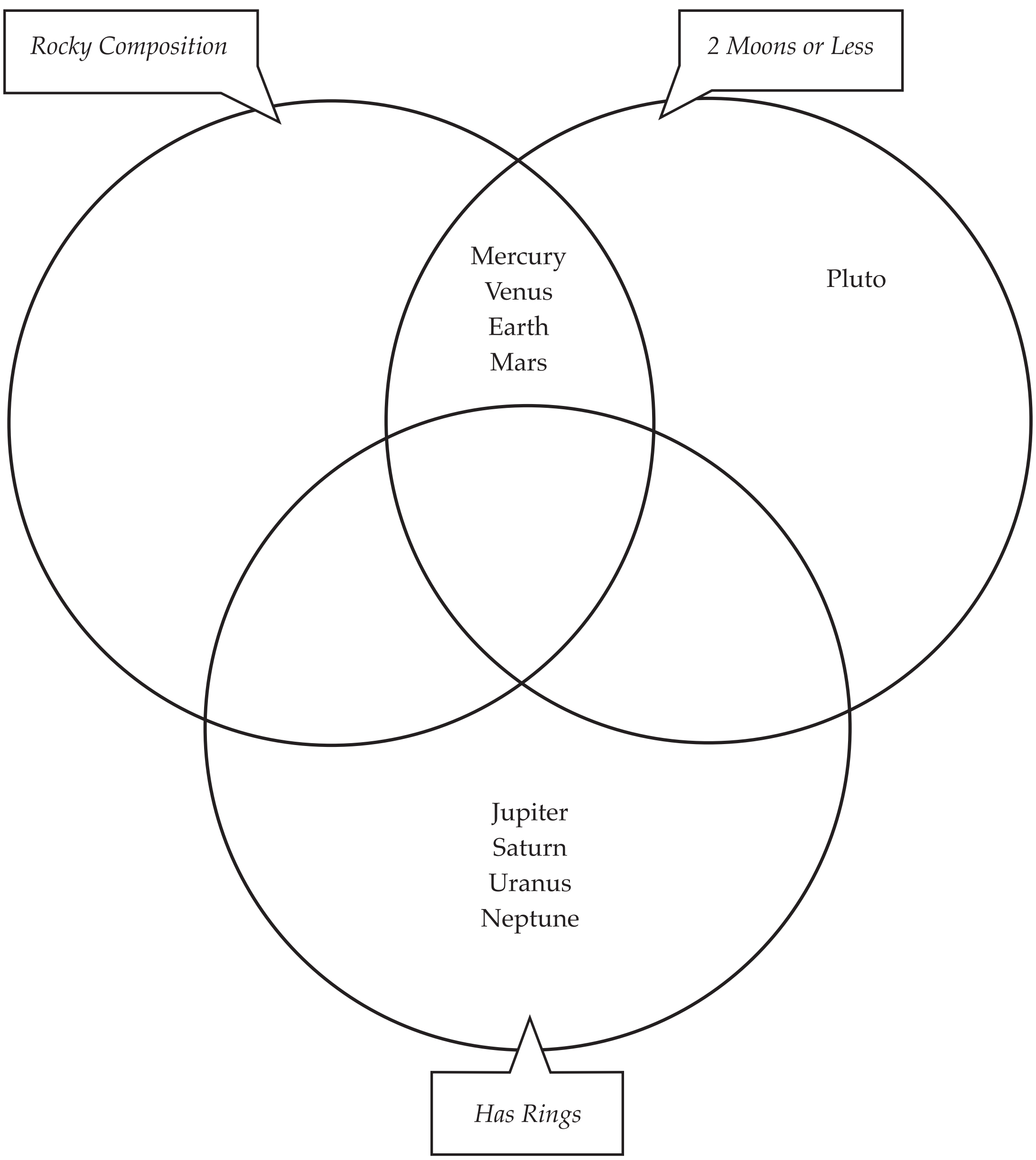
Star Date
stardate.org/resources/ssguide/

Voyage Online
www.voyageonline.org

Teacher Answer Key

Student Worksheet 3




Rocky Composition
2 Moons or Less
Mercury
Venus
Earth
Mars
Pluto
Jupiter
Saturn
Uranus
Neptune
Has Rings

2. The Venn diagrams very effectively organize the themes the class discussed. The planetary characteristics used on the two Venn diagrams were chosen so that the planets fall into identical locations on both diagrams. If students place the planets correctly, they can easily conclude that:
   - Mercury, Venus, Earth, and Mars are: located between the Sun and Asteroid Belt, have a day longer than 20 hours (slow rotators), are Earth-sized or smaller, are rocky, have 2 moons or less, and don't have rings. They are termed the terrestrial (Earth-like) worlds.
   - Jupiter, Saturn, Uranus, and Neptune are: located beyond the Asteroid Belt, rotate in less than 20 hours (fast rotators), are larger than Earth, are not rocky (they are gaseous), have more than 2 moons (actually families of moons), and have ring systems. These are the Jovian (Jupiter-like) planets.

   Students should also conclude that Pluto seems to be in a class all by itself.

   Students must use the planetary characteristics to support their conclusion of two main categories of planets.

Student Worksheet 1: Solar System Catalog

Name ______________________________ Date __________

A catalog allows you to learn many things about the inventory of a store. For example, you can learn what kinds of items they have and at what price. Here's a novel idea—imagine you manage a store called the Solar System. Your job is to create a catalog of the Solar System so we can determine what kinds of objects are contained within it.

Directions:

1. You will need to create a cover page. It must contain your name and a title for your catalog.

2. You will need to research the different components of the Solar System, including:
   - The Sun
   - Planets
   - Moons
   - Comets
   - Asteroids and Meteoroids
   - Kuiper Belt Objects

3. One page in your catalog should be dedicated to each component. Each page should contain the following for the component addressed:
   - Component's name
   - Description of component
   - Average size or size range
   - Composition
   - General location in the Solar System

   An example of the component including a picture—your picture may be a drawn image, a magazine clipping, or printed out from the internet.

4. Use the supplies your teacher makes available to create a catalog that is full of accurate information, as well as neat and creative.

Question

Answer the following question after you have shared your catalog with the class:

Is our Solar System the only solar system, or one of many? Support your answer with information from your research and the class discussion.

____

____

____

____

JOURNEY through the UNIVERSE

Student Worksheet 2: What a Wonderful World

Name ____ Date ___________

Travel agents help people plan vacations to exotic destinations like Hawaii, Fiji, and Finland. However, travel agents of the future may have to help people plan vacations to other spots like Venus, Jupiter, or Mars! Your job is to create a futuristic travel brochure for a planet in the Solar System. Follow the directions below to get started.

Directions:

1. First, you will need to research your planet. Your brochure should contain the following:

- Planet's name
- A picture of the planet
- Nature of planet's atmosphere and climate
- Planet composition—What is it made of?
- Fast Facts
    - The number of the planet in the order of the distance from the Sun
    - Distance from the Sun
    - Length of day
    - Length of year
    - Number of moons
    - Presence of rings
    - Diameter of planet—How big is it compared to Earth?
- Three possible day-long trips on your planet—As a travel agent you should plan your trips based on what is interesting about your planet. For instance, are their any interesting surface features, moons, rings, etc.?
- Three suggested items to bring—What is the atmosphere on your planet like? Will you need an oxygen tank? What is the temperature like? Should you bring a bathing suit, sweater, or both?

2. You will be given supplies and a sheet of 11" x 17" paper to create your brochure. You may design your brochure any way you see fit. Remember to include all of the required information while making it neat and creative.

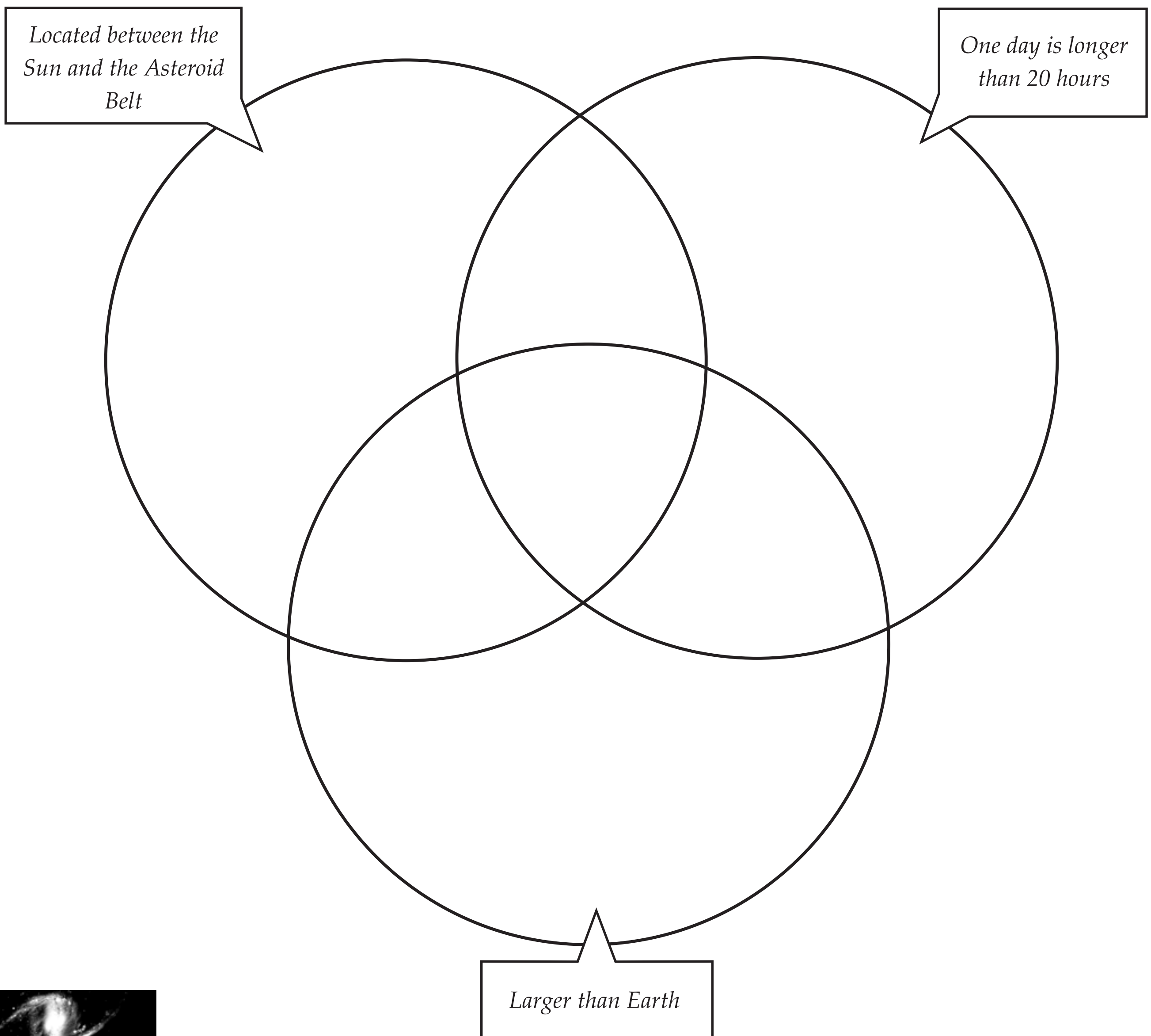
3. Prepare a short 3-5 minute presentation to the class describing your planet. Use your brochure as a visual aid.

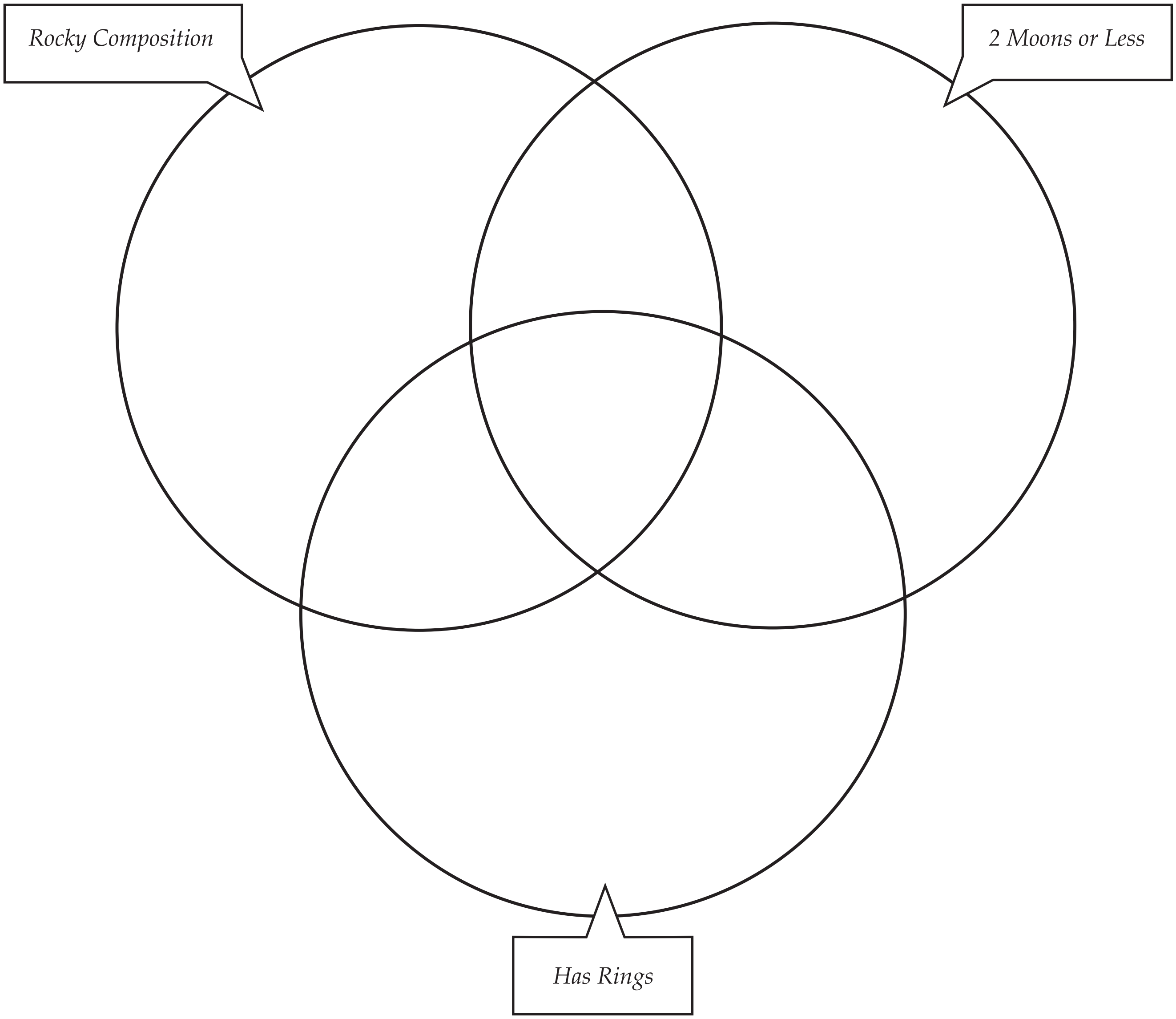
Student Worksheet 3

Name ____ Date ___________

Although each planet is a unique and majestic world, some similarities do exist between them. As a class you came up with several themes that reflect these similarities. The Venn Diagrams below can help to organize these themes.

1. Use information from your research and class discussion to complete the following two Venn Diagrams by placing the planets' names in the correct locations.





2. After you have completed the Venn diagrams, describe below how the planets seem to fit almost entirely within two categories based on the characteristics they share.

JOURNEY through the UNIVERSE

Voyage: A Journey through our Solar System

Grades 5-8

Lesson 2: Voyage of Discovery

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 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 4B1:

We live on a relatively small planet, the third from the sun in the only system of planets definitely known to exist (although other, similar systems may be discovered in the universe).*

* Since the time these standards were written, over 130 stars have been discovered to have planets. For the most up-to-date number, please visit www.exoplanets.org.

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.

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

- 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 nine planets revolving around it. The Solar System also includes the moons of the planets, asteroids, comets, 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 all 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 than the inner planets. 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 is the smallest planet and has the largest average distance from the Sun. Its basic properties—size, composition, orbit around the Sun—make it a poor fit into either the terrestrial or Jovian categories of planets. As a result, it has been suggested that Pluto might not be a planet, but, rather, belong to a group of icy worlds (the first of which was discovered in 1992) in the outer part of the Solar System most commonly called Kuiper Belt Objects (KBOs). 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; it remains the ninth planet.

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.voyageonline.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

	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
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	88 days	225 days	365.3 days	687 days	11.86 years	29.46 years	84.01 years	164.79 years	247.68 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	47	27	13	1
Rotation Period	59 days	244 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 days 9 hours 18 min retrograde*

Numbers in the table are valid as of September 2005.

*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 using the criteria below.

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.

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!

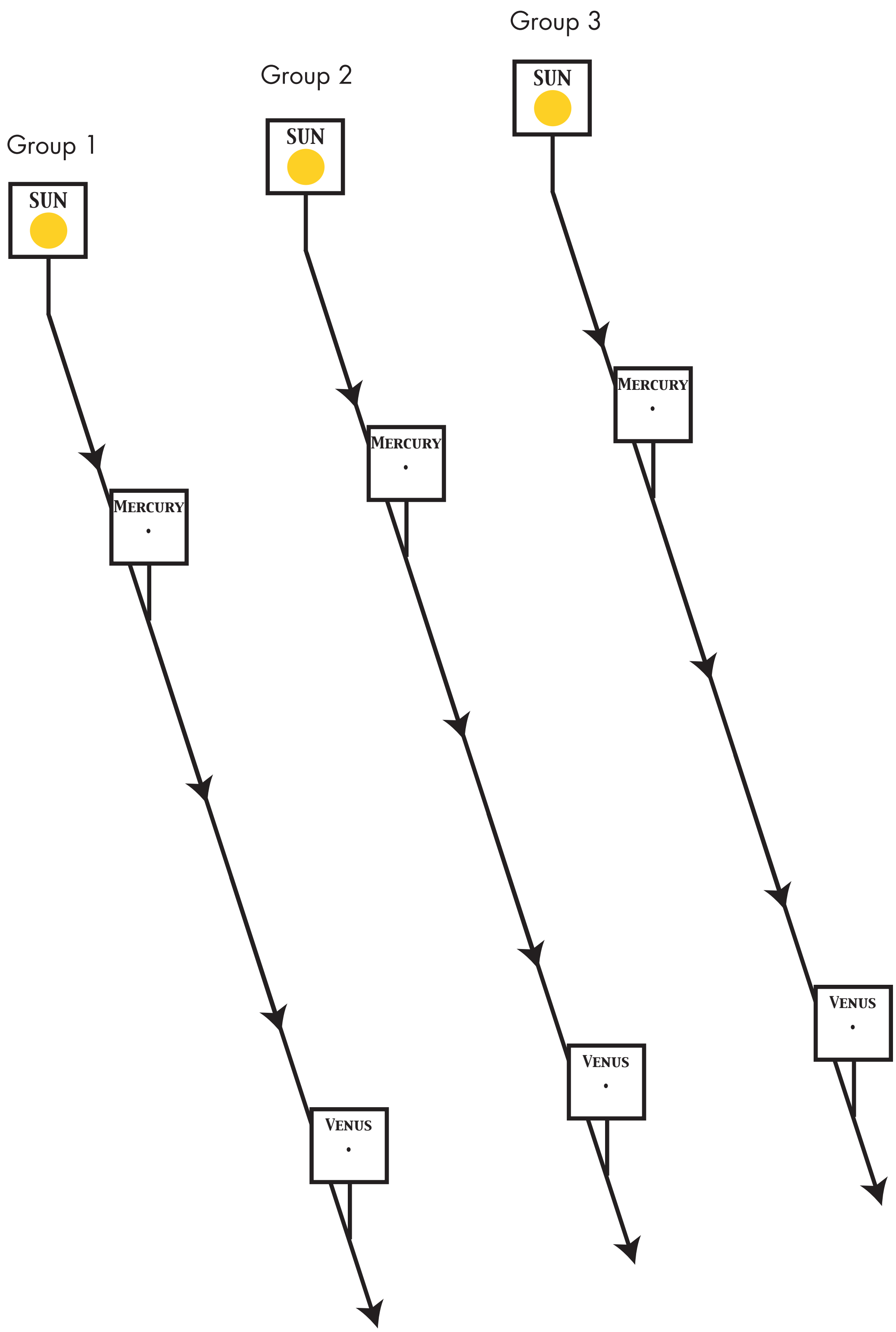


Figure 1. Pacing out the Solar System. Each group places the Sun on the ground, paces the distance to Mercury, places the Model Planet Card on the ground, paces the distance to Venus, etc.

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.

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.

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.

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=a&id=1091

Kids Astronomy
www.kidsastronomy.com/solar_system.htm

NASA Kids
kids.msfc.nasa.gov

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
Benchmarks for Science Literacy
www.project2061.org/tools/benchol/bolframe.htm

The Busy Teacher
www.ceismc.gatech.edu/busyt/astro.html

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

Star Date
stardate.org/resources/ssguide/

Voyage Online
www.voyageonline.org/

Solar System Questions and Fun Facts

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 of the planets—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 Pluto) planets?

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 among the outer 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
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: $\frac{300{,}000{,}000 \text{ m/s}}{10{,}000{,}000{,}000} = 0.03$ 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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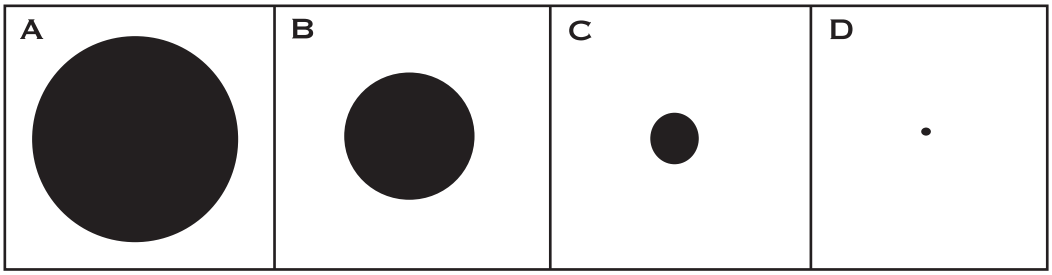
Teacher Answer Key

Student Worksheet 1: Voyage of Discovery

Name ______________________________________ Date __________

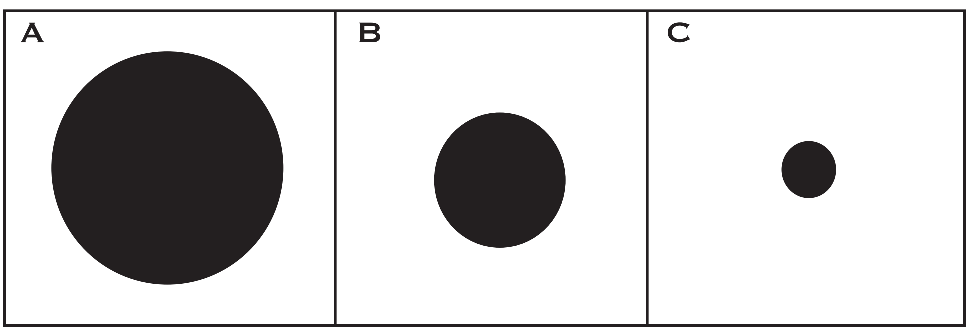
1. If a balloon with a diameter of 14 cm is a model of the Sun, which circle below do you think represents the model Earth? __________



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? ________

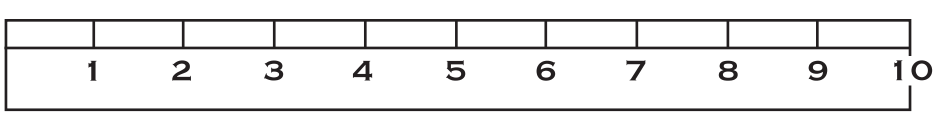


4. Look at your answer for number 1. How far do you think the model Earth should be from the model Sun? __________

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.



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.

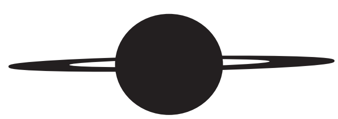
Mercury

Venus

Earth

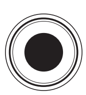
Mars

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.)

Student Worksheet 3: Voyage of Discovery

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.

JOURNEY through the UNIVERSE

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

Voyage: A Journey through our Solar System

Grades 5-8

Lesson 3: How Far is Far?

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 3: How Far is Far?

Lesson at a Glance

Lesson Overview

Students will determine the actual distance to the Sun and the Moon without ever leaving the Earth, and in doing so will gain a better understanding of the huge distances in the Earth-Sun-Moon system. In order to determine these distances, students will apply their understanding of mathematical models in two different ways, using a single mathematical principle.

Lesson Duration

Two to three 45-minute class periods

Core Education Standards

National Science Education Standards

Standard A2: Understandings about scientific inquiry

- Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.
- Mathematics is important in all aspects of scientific inquiry.

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 2B1:
Mathematics is helpful in almost every kind of human endeavor—from laying bricks to prescribing medicine or drawing a face. In particular, mathematics has contributed to progress in science and technology for thousands of years and still continues to do so.

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 Question

- How can we use models to measure the relative distances between the Sun, the Earth, and the Moon?

Concepts

Students will learn the following concepts:

- We can use objects like the Sun or Moon, and models of the Sun and Moon, as rulers.
- We can use models to study things that are big, like the Sun or the Moon.
- Similar triangles have angles that are the same and sides that are proportional.
- The distance to the Sun and the Moon can be determined without ever leaving the Earth.

Objectives

Students will be able to do the following:

- Determine the distance to the Sun using a pinhole tube.
- Determine the distance to the Moon using a model of the Moon.
- Use models and similar triangles to explore the Earth-Sun-Moon system.

Science Overview

The brightest objects in the sky are the Sun and the Moon. The Sun creates the daily rhythm for all life forms living on or near the surface of Earth by determining whether it is day or night. The Moon is Earth's celestial neighbor; it is the brightest object in the night sky and sometimes can even be seen during the day. In exploring the cosmic neighborhood of the Earth, it is natural to begin with the Sun and the Moon.

The Sun: The Supreme Ruler of the Solar System

The Sun is at the center of the Solar System. The nine planets and their moons as well as the smaller bodies—such as asteroids and comets—all revolve around the Sun. The Sun's role as the center and supreme ruler of the Solar System comes from its high mass: it has 99.8% of the mass in the system and, therefore, guides the movement of the other objects via gravitational forces. Sunlight brings energy to the rest of the Solar System and largely determines the conditions prevalent at the planets, from making the sunlit side of Mercury bake in 427ºC (800ºF) heat to providing the hospitable environment for life on Earth.

The Sun is a fairly typical star, just one of over 200 billion stars in the Milky Way galaxy. It is not among the brightest or the faintest stars. Even though it is more massive than about 96% of the stars in the Milky Way, there are billions of stars more massive than the Sun. The Sun is made up entirely of gas, mostly of hydrogen (91% of the atoms) and helium (8.9%), with heavier elements such as oxygen, carbon, neon, and nitrogen mixed in to make up the remaining 0.1%. The Sun is powered by nuclear fusion occurring at its center; in this process, hydrogen atoms are converted into helium, with energy released as a by-product.

The Sun's diameter is about 1.4 million km (865,000 miles), roughly 109 times Earth's diameter. This is the same ratio as between the height of an NFL linebacker (185 cm) and the size of a honey bee (1.7 cm). The Sun is about 150 million km (93 million miles) away from Earth. The situation is similar to the honey bee hovering about two football fields away from the linebacker. The mass of the Sun is 1.99×10^{30} kg, or about 333,000 times Earth's mass. This is the same ratio as between a linebacker (100 kg) and three honey bees (0.1 g each).

When the Sun is observed with instruments (the Sun should never be looked at directly), it appears to have a surface (see Figure 1). But since the Sun is made entirely of gas, it does not have a solid surface like Earth does. Instead, the apparent surface of the Sun is the region

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where the light that can be seen starts its journey into space and where the visible solar features appear. The behavior of the features on the Sun's surface is regulated by the Sun's activity cycle, the progression of which can be followed by counting the number of sunspots visible on the Sun's surface. The sunspot number changes from a minimum to a maximum and back to a minimum over the solar activity cycle, with an average period of about 11 years.

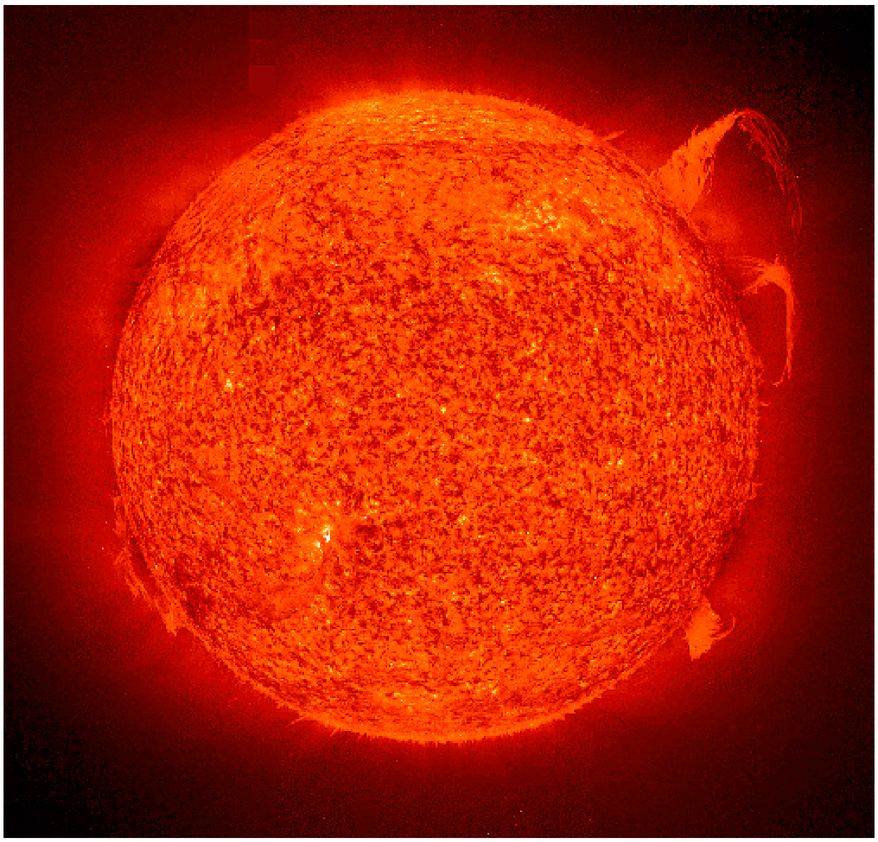

Figure 1: The Sun seen in extreme ultraviolet wavelengths. (Picture credit: NASA/SOHO; http://sohowww.nascom.nasa.gov/bestofsoho/hooksG.gif)

The Life and Times of the Sun

The formation of the Sun began when a dense region of a slowly spinning cloud of gas and dust in space began to contract under its own gravity. In the central part of the cloud, an infant Sun was born, and around it, a rapidly spinning disk was formed. The disk fed material onto the growing infant Sun, while at the same time, small dust grains within the disk grew to become planetary building blocks, and eventually whole planets. The temperature inside the developing Sun grew until nuclear fusion, the power process of the stars, began at its center. At this time, about 4.6 billion years ago, the Sun became a young star.

The Sun has been burning hydrogen ever since and has enough fuel for another 5 billion years or so. When the Sun runs out of fuel at its center, its outer layers will expand in the so-called red giant phase of its life, and engulf the orbit of Earth. Later on, the aging Sun will cast off its outer layers in the form of a shell-like planetary nebula, while the remaining parts will become a dense object called a white dwarf. The white dwarf will slowly fade and after a few billion years will become a very faint object called a black dwarf: this will be the final fate of the Sun.

Sun's Effect on Earth

The Sun provides most of the energy on Earth. Without the Sun, the Earth would be cold and lifeless. On Earth, sunlight is absorbed by the ground, the seas, and the atmosphere. It drives air flows in the atmosphere and currents in the oceans, and greatly influences climate and weather. It is the most important source of energy for life on Earth; it provides energy for photosynthesis and, therefore, supports the first link in many of the food chains on Earth. It is possible for life to exist in places without sunlight (such as at the bottom of the oceans), but most of the life with which we are familiar uses the energy provided by sunlight in one way or another.

The fact that the Earth is capable of supporting a wide variety of life forms is due to its distance from the Sun. When objects move farther away from the Sun, they receive less sunlight and their temperatures drop. Earth is at just the right distance from the Sun so that liquid water can exist on its surface. Liquid water is thought to be essential for the existence of life forms, but it is liquid only in a small temperature range, from 0ºC (32ºF) to 100ºC (212ºF), depending on factors such as pressure and impurities in the water. If the Earth were at a different distance from the Sun, it is possible that life would never have developed here!

Earth's orbit around the Sun is nearly circular. That means that its distance from the Sun does not vary much during the year. The average distance from the Earth to the Sun is about 150 million kilometers (or 93 million miles). This is a huge number and even astronomers prefer to use numbers a little more manageable. They have defined the unit for distances in the Solar System to be the average Earth-Sun distance: Astronomical Unit (AU). The closest distance that the Earth gets to the Sun (a point in Earth's orbit called perihelion) is 0.98 AU, and the farthest (called aphelion) is 1.02 AU; the variation in the distance is minimal. The orbits of the other planets in the Solar System are nearly circular, as well, with two exceptions: Mercury and Pluto.

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The Moon

The Moon is Earth's celestial neighbor. It is about 384,000 km (239,000 miles) from the Earth, and its diameter is about one quarter of Earth's. By comparison, if a standard-sized (23 cm or 9 in) Earth globe (or a basketball) represents the Earth and a baseball represents the Moon, then the baseball would be 30 Earth diameters (6.9 m) away. Another way to bring the distances to a more manageable scale is to use a one to 10 billion scale model, as is done with *Voyage*, a scale model of the Solar System, located on the National Mall in Washington, D.C. In this case, the distance between the Earth and the Moon is 3.84 cm (1.5 in), Earth's diameter is 1.3 mm (0.05 in), and the Moon's, 0.35 mm (0.01 in). The orbits of the planets closest to Earth (Venus and Mars) would be about 4 m (13 ft) and 8 m (26 ft) away, and the Sun would be located at a distance of about 15 m (49 ft). Compared with the other objects in the Solar System, the Moon is basically just a hop and a skip (or at least a few days' rocket ride) away from the Earth.

It takes the Moon 27 $^1/_3$ days to go once around the Earth. The Moon's distance from the Earth varies during its orbit. The closest approach of the Moon to the Earth (a point in its orbit called perigee) is 363,000 km (226,000 miles), and the farthest point (called apogee) is 405,500 km (252,000 miles): a total distance change of 11% during one orbit. The Moon's orbit around the Earth is much more oval-shaped than the Earth's orbit around the Sun. Consequently, the size of the Moon seen in the sky varies by about 11% during a month–in contrast, the Sun's apparent size in the sky changes by only 3% during a year.

The Moon's composition is very similar to those of Earth and the other rocky, Earth-like planets in the Solar System. In fact, its similar composition to the Earth's crust material was a crucial clue in developing an understanding of its origin. The Moon is thought to have formed when a Mars-sized object smashed into the forming Earth billions of years ago. Material was blasted into orbit around Earth by this collision and later collected together to become the Moon. Exactly how this process occurred is still being investigated.

The surface of the Moon (see Figure 2) is heavily cratered as a result of meteoroid bombardment in the past. Large meteoroid impacts were common in the early history of the Solar System, when the leftover chunks of rocky material from its formation collided with the developing planets and moons. Most solid bodies in the Solar System have heavily cratered surfaces. Sometimes these craters have been filled with lava flows, and traces of most craters on Earth have been erased by geologic activity during the planet's history. But even on Earth, signs of meteoroid impacts from the past are visible; for example, many lakes are originally impact craters that were later filled with water. There are two main types of terrain on the Moon: the old, light-colored, heavily cratered highlands, and the younger, dark, smooth areas called maria.

Figure 2: A computer-generated color picture of the Moon based on data taken by the Galileo spacecraft in 1990. (Picture credit: http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/gal_p37329.html)

Humans on the Moon

The Moon is the only heavenly body that humans have ever visited (as opposed to robotic spacecraft making observations or taking samples). Between 1969 and 1972, six Apollo spacecraft landed on the Moon: Apollo 11, 12, 14, 15, 16, and 17. Apollo 13 had a mishap on its way to the Moon and, after an ingenious rescue effort, returned safely to the Earth, but without making the planned Moon landing. The Apollo missions brought back a total amount of 382 kg of rock samples from the surface of the Moon. Studies of these samples in laboratories here on Earth have revealed lots of information about the composition, the structure, and the history of the Moon.

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Eclipses

Even though the Sun and the Moon are very different in size (Sun's diameter of 1.4 million km; 865,000 miles, vs. Moon's 3,500 km; 2,200 miles), the Moon is so much closer to the Earth than the Sun that the angular size (the angle of the sky they appear to cover) of the two celestial objects as seen from the surface of Earth is the same. This is a manifestation of the optical effect where nearby small objects appear bigger than larger objects farther away (see Figure 3).

As a result of the same angular size of the Sun and the Moon, interaction between these two objects in the sky as seen from the surface of Earth, gives rise to eclipses. On its orbit around the Earth, the Moon may pass in front of the Sun (as seen from the surface of Earth) and cast a shadow on the surface of Earth. Within the shadow, the Moon appears to block the Sun in the sky, giving rise to a total eclipse of the Sun. Nearby regions may be only in partial shadow (that is, only part of the Sun appears to be blocked by the Moon): this event is observed as a partial eclipse. Other parts of the Earth not touched by the Moon's shadow do not observe any eclipse at all. This is because the Moon's shadow covers only a small region on the Earth's surface—at most, 267 km (or 166 miles) across.

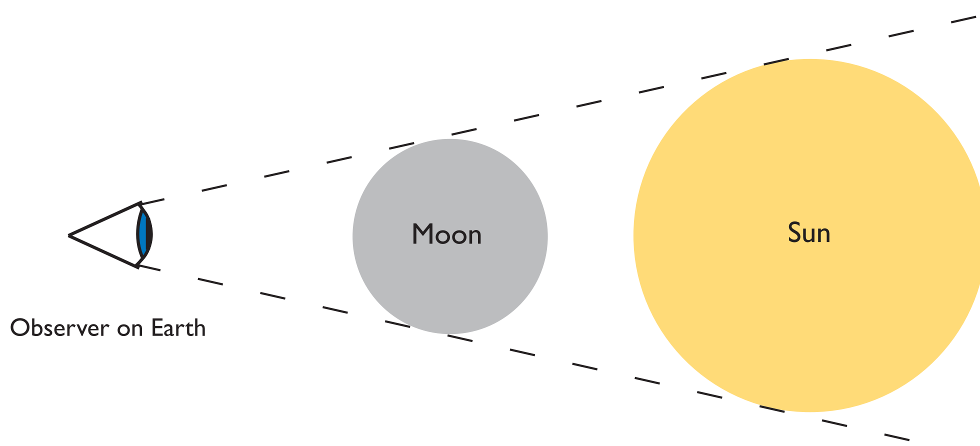

Figure 3. The angular sizes of the Moon and the Sun are the same to an observer on Earth. This is because the Sun, a much larger object than the Moon, is much farther away from Earth. NOTE: Objects and distances in the figure are not drawn to scale. REMEMBER never to look directly at the Sun.

The Moon's orbit may take it through Earth's shadow. A lunar eclipse occurs when the sunlight-illuminated surface of the Moon is shaded by Earth's shadow. Just as with a solar eclipse, a lunar eclipse may be total or partial, depending on whether Earth's shadow covers the whole visible surface of the Moon or just part of it.

Measuring the Distances to the Moon and the Sun

Measuring the distances to the brightest objects in the sky has been a goal for generations of astronomers. For example, ancient Greeks (such as Aristarchus of Samos, 310-230 B.C.) were attempting to measure the distance to the Moon based on the timing of lunar eclipses, and the distance to the Sun based on the phases of the Moon. The results were not very accurate, but the ingenuity of constructing methods to measure these distances in ancient times is admirable. The phases of Venus were used at later times to measure the distance to the Sun.

In modern times, the distance to the Moon has been measured accurately using retroreflectors left behind by the Apollo 11, 14, and 15 missions. Retroreflectors are suitcase-sized devices constructed of mirrors so that they always reflect a light beam back into the direction from which it came. When a laser beam is aimed at the Moon's surface, the devices reflect it back to Earth. Measuring the beam's travel time and using the speed of light gives a distance to the Moon to an accuracy of a few centimeters. The distances to nearby planets can be measured by radar observations: the time it takes for a radio signal to travel to a planet and bounce back to Earth from the planet's surface tells how far the planet is located. Using the distances to the planets derived this way (Venus, for example, is often used for this purpose), the distance to the Sun can be calculated using geometry.

It is relatively easy to get an estimate of the distance to the brightest objects in the sky using their sizes as the basic ruler, but it is very difficult to get accurate results. Scientific measurements have sources of error. One of the goals of repeated measurements and improved techniques is to take these sources of error into account and achieve more accurate results. An understanding of the basic physics that guides the behavior of planets can provide information on their relative distances. Making accurate measurements is much more difficult and requires modern technology.

The situation gets even more difficult when determining distances beyond the Solar System, since there is little hope of taking instruments to make measurements much beyond the Solar System anytime soon. Instead, scientists have to rely on understanding of astronomical phenomena to estimate distances within Milky Way and throughout the Universe. Using this process creates a distance ladder, where measurements of nearby distances are used as a basis on which the next step—going farther—is based. This means that measuring the distances to the cosmic neighbors of the Earth is the first step in understanding the distances between celestial objects. Ultimately, this journey of discovery will lead to determining the distances to stars, distances between galaxies, and ultimately the scale of the Universe.

NOTES:

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Photograph (See *Preparation and Procedures* for suggestions.)
- Enlargement of the same photograph
- Photograph with objects at different distances

Preparation & Procedures

1. Find a photograph of just one object, in which the picture of the object is much smaller than the actual object. For example, a picture of person is smaller than the real person.

2. Enlarge the photograph on a copier so that the picture of the object is now larger than the actual object. For example, enlarge the picture of the person so that the image of their face is much bigger than their real face.

3. Find another photograph of at least two objects at various distances, so that the object closer to the camera appears larger than a bigger object farther away. For example, a car in front of a house may look bigger than the house, even though in reality it is not.

4. Discuss with students how a photograph is a model. In what way is it a model? *(Desired answer: a photograph is a model because it represents another object)*

5. Ask students whether a photograph of an object is the same size as the actual object. *(Desired answer: usually no)* Show students the photograph of an object that is smaller than the real object and the same photograph enlarged on a copier so that it is bigger than the real object. Show students a photograph where an object closer to the camera appears larger than a bigger object farther from the camera. Ask students which model more accurately represents the object(s) in the picture, the first photograph or the last photograph. *(Desired answer: the latter picture is not proportional, and is therefore not as accurate a model)*

6. Tell students that the first photograph is actually a "scale model." Ask students to define this term. *(Desired answer: these are models that are proportional in size to the original)* For example, if you find that the length of your face in a photograph is ten times the diameter of your eye in the photograph, then your actual face should be five times the diameter of your actual eye.

Activity 1: Sun – Ruler of the Solar System

In this activity, students create a pinhole tube and use it to make a model of the Sun. They will then use this model and similar triangles to determine the distance from the schoolyard to the Sun.

Teacher Materials

- Tree Transparency (from back of lesson)
- Sun Transparency (from back of lesson)
- Overhead projector

Student Materials (per student)

- Student Worksheet 1
- Cardboard paper towel tube
- Aluminum foil square (10 cm x 10 cm)
- Graph paper square (10 cm x 10 cm)
- 2 rubber bands
- Thumbtack or pin
- Metric ruler
- Sharp pencil
- Yard stick or meter stick
- Masking tape
- Calculator
- Optional: Markers, stickers, other materials to decorate pinhole tube

Preparation & Procedures

1. Be sure to try this activity ahead of time. It takes some practice. Do not wait for the night before—you will not have the Sun available for practice.

2. You can only do this activity on a sunny day.

3. Cut aluminum foil and graph paper into approximately 10 cm (4 in) squares. Cut enough for each pair of students with extras—aluminum foil tears easily.

4. Make an overhead transparency of the Tree Transparency and Sun Transparency located in the back of the lesson. (You will need to make a transparency of the Moon Transparency in Activity 2, so you may want to make them all at once.)

5. Encourage students to think about how a camera works. You can use the following facilitation to guide students to understand what a camera is actually collecting.

   Tell students that you want to take a picture of a tree. Ask them if the camera is actually collecting the real tree? *(Desired answer: no, it is collecting an image of the tree)* Ask students if you could take a picture of the tree in the dark. *(Desired answer: no)* If this is the case, then what is the camera actually collecting? *(Desired answer: light reflected from the tree)* Ask students if the tree is giving off its own light. *(Desired answer: no, it is reflecting light from the Sun)*

6. Once students realize that cameras are collecting the light reflected from objects, you can use the facilitation below to help them understand how this happens.

   Draw a picture of a simple tree on the blackboard, similar to the tree on the Tree Transparency. Opposite the tree, draw a box and tell students this represents the camera. Ask them what we need if we're going to collect light reflected from the tree. *(Desired answer: a hole in the front of the box)* Draw the hole. Draw a line from the top of the tree through the hole. This represents the light reflected from the top of the tree. Draw another line for the light reflected from the bottom of the tree. (Be sure that students understand that light is being reflected by the tree in all directions, but the camera only collects the light being reflected in the direction of the camera.) Ask students what the image will look like in the back of the camera. *(Desired answer: it will be upside-down because the light from the top of the tree will end up at the bottom of the camera, and vice versa)* Draw an upside-down tree in the back of the camera.

7. The image taken by a camera is actually a scale model of the real image. By using the Tree Transparency and the facilitation below, you can prove this to students by using the properties of similar triangles.

   Cut out the small triangle on the bottom of the Tree Transparency. Display the Tree Transparency using the overhead projector; it should look just like the drawing you created on the board. Ask the students what they notice about the two triangles in the picture. *(Desired answer: they are* *similar)* If the students do not know the answer, it is okay. Similar triangles are triangles that have the same angles, thus making the length of their sides proportional to one another. Show students that the cut-out triangle is identical to the small triangle in the picture, by placing them on top of one another. Flip over the cut-out triangle and place it inside of the big triangle. Move the cut-out triangle around the inside of the big triangle to show the students that the angles are identical to the angles in the big triangle, proving that they are similar. Remind the students of the rules of similar triangles; the angles are the same, and the sides are proportional to one another. Ask the students, if the small triangle is proportional to the big triangle, then what does that make the small triangle? *(Desired answer: a scale model of the big triangle)* Hint: If the students need help, remind them of the *Warm-Up & Pre-Assessment* discussion of scale models. Discuss how this means that the picture of the tree will then be proportionately smaller than the actual tree, making it a scale model.

8. Students will now make a camera of their own. You can use the following facilitation in order for students to design their own camera and experiment.

   Display the materials in the student materials list, and ask students if there is anything they can use to build a camera. *(Desired answer: the paper-towel tube can be used as the box)* Ask students what they can use to make the front of the camera. *(Desired answer: they will need an opaque material for the front of the tube with a small hole in it, like aluminum foil, which will only allow light to enter through the hole)* Ask students what they can use to display the light on the back on the camera. *(Desired answer: paper)* When students select paper for the other end of the tube, ask them how they are going to see the image that would be projected on the inside of the pinhole tube. *(Desired answer: paper is translucent when enough light falls on it)* Then ask students what they should take a picture of to ensure that they will see an image on the other side. *(Desired answer: the Sun should be bright enough to be seen)*

9. Direct students to work in pairs to assemble a pinhole tube. See Part I of Student Worksheet 1 for student procedures.

10. Students can use their pinhole tubes to create a scale model of the Sun. You can use the facilitation below to guide students to this conclusion.

    Display the Sun Transparency; it should remind students of the Tree Transparency. Discuss how, if the triangles were similar in the Tree Transparency, these triangles should also be similar. To prove this, follow the same procedure for the small triangle on the bottom of the Sun Transparency as you did with the Tree Transparency. Once it has been established that the triangles are similar, ask students what the image of the Sun is in comparison to the real Sun. *(Desired answer: it is a scale model of the real Sun)*

11. Students can use the diameter of the Sun as a ruler to measure the distance from the Sun to the Earth. Use the following facilitation and the Sun Transparency to help students develop the procedure.

    Ask students if the model Sun is proportional to the real Sun, then what is proportional to the distance between the Sun and the Earth (front of the pinhole tube). *(Desired answer: the length of the pinhole tube)* Ask students how they could determine the distance from the Sun to the Earth using Sun diameters. Hint: Use the model Sun and the pinhole tube. *(Desired answer: the number of model Suns that will line up along the length of the pinhole tube will be equal to the number of real Suns that will fit between the Sun and the Earth)* Ask students what information they will need and how they will obtain it. *(Desired answer: the only things they need to know in order to determine the distance is the length of the tube, which they can measure, and the size of the model Sun, which they can get by using their pinhole camera to make a model the Sun)*

12. Direct teams to work outside and use the pinhole tube to find the image of the Sun. See Part II of Student Worksheet 1 for student procedures.

    Warn students not to use the pinhole tube as a telescope to look directly at the Sun. NEVER look directly at the Sun; doing so can cause permanent eye damage.

CURRICULUM CONNECTION

Social Studies: Have students research whether Galileo Galilei went blind from staring at the Sun.

How Far is Far?

Lesson at a Glance

Science Overview

Conducting the Lesson

Warm Up & Pre-Assessment

Activity 1: Sun – Ruler of the Solar System

Activity 2: A Model Moon

Lesson Wrap-Up

Resources

Assessment Criteria for Activity 1

5 Points

- All calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 1 demonstrates an accurate and thorough understanding of scientific concepts underlying the lesson.
- Work is presented in a neat, clear, and organized fashion that is easy to read.

4 Points

- Most calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 1 demonstrates an accurate and thorough understanding of almost all scientific concepts underlying the lesson.
- Work is presented in a neat, clear, and organized fashion that is usually easy to read.

3 Points

- Some calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 1 demonstrates an accurate and thorough understanding of most scientific concepts underlying the lesson.
- Work is organized but may be hard to read at times.

2 Points

- Few calculations are shown and the results are correct and labeled.
- Student Worksheet 1 demonstrates an accurate and thorough understanding of some scientific concepts underlying the lesson.
- Work is somewhat organized but hard to read.

1 Point

- Few calculations are shown and the results are accurate and labeled.
- Student Worksheet 1 demonstrates an accurate and thorough understanding of a few scientific concepts underlying the lesson.
- Work is appears sloppy and is hard to read.

0 Points

- No work was completed

Reflection & Discussion

Ask students to report their results: How far away is the Sun, in terms of Sun diameters? Ask the students what else they needed to know in order to express this distance in kilometers. (*Desired answer: the diameter of the Sun*) Ask students to predict how much bigger the Sun is than the Earth. After taking a few suggestions, tell them that its diameter is about 100 times bigger than the Earth's; this means that you could line up 100 Earths across the Sun! Now that they have an idea of the size of the Sun, they can appreciate how far away Earth is from the Sun in Sun diameters. (*Fun Fact: The Sun is so far away that if you were to fly at the speed of a commercial jet plane to the Sun, it would take 17.5 years to get there!*)

Transfer of Knowledge

In order to assess student understanding of similar triangles, allow them to apply what they have learned by having them complete questions 4 and 5 in Student Worksheet 1. (Answers are in *Teacher Answer Key*)

Extensions

- Students may be able to see sunspots on their image of the Sun. Have students research what sunspots are and why they occur. Students should describe how the number of sunspots shows the cyclical nature of the Sun.
- Have students research how the Sun affects the Earth. For example: seasons, climate, night and day, etc. (See *Science Overview* for examples.)
- Have students research how we can harness the Sun's energy to produce power here on Earth.

Placing the Activity Within the Lesson

This activity should help students understand the magnitude of the distance to the Sun. Students should also be aware that they can learn things about the Sun without ever leaving the Earth. Discuss with students whether they can do exactly the same experiment for the Moon. They cannot measure the distance in exactly the same way, since the Moon is not bright enough to give an image through the paper in the back of the pinhole tube. Have them brainstorm how they can use the same concept of a model to measure the distance to the Moon.

Notes on Activity 1:

Activity 2: A Model Moon

In this activity, students will create a Moon-viewer and use it, along with models and the principle of similar triangles (which they learned in Activity 1), to determine the distance to the Moon.

Teacher Materials

- Moon Transparency (from back of lesson)
- Overhead projector

Student Materials (per student)

- Student Worksheet 2
- Index card
- Transparent tape
- 3 meters of string
- Metric ruler
- Scissors

Preparation & Procedures

1. See the Moon Visibility Tables in the back of the lesson for optimal viewing times during the school year.

2. Ask students how big they think the Moon is compared to the Earth. After taking a few suggestions, tell them that it is about one quarter the size of Earth. Ask them how many Moons you would have to line up in order to get the distance between the Earth and the Moon. Take some suggestions, and write their answers on the board for later comparison.

3. Students will use the same principles of models and similar triangles that they used in Activity 1 to calculate the distance to the Moon. Remind the students of the rules of similar triangles: corresponding angles are always the same and corresponding sides are always proportional. Put the Sun Transparency back on the overhead projector, and remind students how they used similar triangles to solve for the distance to the Sun. Ask for suggestions as to how this could be adapted to discover the distance to the Moon. Now put the Moon Transparency on the overhead projector and compare it to their answers. Cut out the small triangle at the bot-

tom of the transparency, and show students how the same principle of similar triangles is used to determine the distance to the Moon.

4. Have students create a Moon-viewer according to the directions in Student Worksheet 2. As a homework assignment, the students will collect and record the appropriate data and complete the required calculations and questions on Student Worksheet 2.

TEACHING TIP

If students do not have a Moon-facing window, they may choose to mount the index card on a stick or other temporary device and perform the activity outdoors.

REFLECTION & DISCUSSION

Ask students how their predictions for the Moon's distance compared to the actual distance. Did anything surprise them? Have students brainstorm situations where knowing how to calculate distances, using this method, might be helpful.

TRANSFER OF KNOWLEDGE

Ask students to identify similarities and differences between the method used to determine the distances to the Sun and Moon. Ask students to describe the strengths and weaknesses of both.

Suggestions for answers:
Both methods used the same principle of similar triangles to find the distances. The method used for the Sun would not work for the Moon. The Moon would project an image, but it probably would not be bright enough to be seen through the paper at the back of the pinhole tube. Both methods work for their purposes, but we could not use the method for the Sun with the Moon, and we could not use the method for the Moon with the Sun (it would hurt our eyes).

CURRICULUM CONNECTION

English: Ask students to write a journal entry exploring their feelings of their place and role in the Solar System.

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Warm Up & Pre-Assessment
Activity 1: Sun – Ruler of the Solar System
Activity 2: A Model Moon
Lesson Wrap-Up
Resources

Assessment Criteria for Activity 2

5 Points

- All calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 2 demonstrates an accurate and thorough understanding of scientific concepts underlying the lesson.
- Work is presented in a neat, clear, and organized fashion that is easy to read.

4 Points

- Most calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 2 demonstrates an accurate and thorough understanding of almost all scientific concepts underlying the lesson.
- Work is presented in a neat, clear, and organized fashion that is usually easy to read.

3 Points

- Some calculations are shown and the results are correct and labeled appropriately.
- Student Worksheet 2 demonstrates an accurate and thorough understanding of most scientific concepts underlying the lesson.
- Work is organized but may be hard to read at times.

2 Points

- Few calculations are shown and the results are correct and labeled.
- Student Worksheet 2 demonstrates an accurate and thorough understanding of some scientific concepts underlying the lesson.
- Work is somewhat organized but hard to read.

1 Point

- Few calculations are shown and the results are accurate and labeled.
- Student Worksheet 2 demonstrates an accurate and thorough understanding of a few scientific concepts underlying the lesson.
- Work is appears sloppy and is hard to read.

0 Points

- No work was completed.

Extension

Have students research the orbit of the space shuttle and compare it with that of the Moon. Ask students why they think we have flown humans to near-Earth orbit more often than to the Moon? Have students research the Apollo missions that flew to the Moon, and any difficulties they may have faced along the way. (Fun Fact: If the Earth were the size of a standard globe, then the space shuttle would orbit less than one centimeter from its surface!)

Placing the Activity Within the Lesson

Students have now used the same principles of similar triangles and models to determine the distance to two objects using two different methods. They should understand that these principles, and other uses of models, can be powerful tools for learning.

Notes on Activity 2:

Lesson Wrap-Up

Assessment Criteria for the Lesson

5 Points
- Student used similar triangles to find the answer.
- Student showed work.
- Student's final answer was correct.
- Student explained his or her reasoning.

4 Points
- Student used similar triangles to find the answer.
- Student showed work.
- Student's final answer was flawed.
- Student explained his or her reasoning.

3 Points
- Student used similar triangles to find the answer.
- Student showed most work.
- Student's final answer was flawed.
- Student explained his or her reasoning, but it was not logical.

2 Points
- Student used similar triangles to find the correct answer.
- Student did not show work.
- Student's final answer was flawed.
- Student explained their reasoning, but it was not logical.

1 Point
- Student did not use similar triangles to find the correct answer.
- Student did not show work.
- Student's final answer was flawed.
- Student did not explain their reasoning.

0 Points
- No work completed.

Extensions for the Lesson

Have students research how early astronomers determined the distance to the Sun and Moon. How do their techniques compare to the one used in the lesson?

Transfer of Knowledge for the Lesson

The Moon and the Sun have almost the same apparent size in the sky—this is why total eclipses can occur. If the Sun is 400 times farther away from Earth than the Moon, figure out how much bigger the Sun is than the Moon. (Hint: Use similar triangles!) Explain your answer.

Answer:

Imagine a triangle extending from a camera to both edges of the object you are looking at (like the Sun or Moon). The small angle in the triangles is the object's angular size. If two objects have the same angular size, this means that if we put these triangles inside of one another, we can see that all three angles are the same, which means that the triangles are similar. That means that their sides are proportional to one another, and if one side (distance to Sun) is 400 times longer than its corresponding side (distance to Moon), then another side (diameter of Sun) is 400 times larger than its corresponding side (diameter of Moon). Therefore, the Sun's diameter is 400 times larger than the diameter of the Moon. Students should be able to draw these triangles to aid in their analysis. However, be aware that it would be very difficult to make these drawings to scale, since the distances are so large compared to the objects, see Figure 3 in the Science Overview *for an example.*

Lesson Closure

1. Help students compare the distance from the Earth to the Sun with the distance from the Earth to the Moon. If the Earth is the size of a basketball, then the Moon is four times smaller, about the size of a baseball. The distance between them is 30 Earth diameters, or about the distance across a large room. On this scale, the Sun would be about the size of a house, 100 times bigger than Earth. It would be located 107 houses away, or almost two miles. Discuss how the distance to the Moon is much smaller than the distance to the Sun.

2. Discuss with students the units of their measurements. Were they traditional units, such as meters or feet? *(Desired answer: no, their measurements were made in terms of Sun or Moon diameters)* Discuss with students how anything can be used as a ruler, as long as we define what our ruler is. Ask students what the advantages of this may be. *(Desired answer: one advantage is that it is easier to understand the distances to objects that are very far away if we use rulers that are familiar to us. For example, we could say that a comet can travel 186 miles per second, or we could say that at this speed, you could travel from Washington, D.C., to Los Angeles, CA, in just 15 seconds!)*

Resources

Internet Resources & References

Student-Friendly Web Sites:

Amazing Space – Sun Facts
    amazing-space.stsci.edu/resources/fastfacts/sun.php
How Distant is the Moon?
    www-istp.gsfc.nasa.gov/stargaze/Shipparc.htm

Teacher-Oriented Web Sites:

American Association for the Advancement of Science, Project 2061 Benchmarks for Science Literacy
    www.project2061.org/tools/benchol/bolframe.htm
Determining the Distance to the Moon
    www.stardate.org/resources/ssguide/moon.html
The Earth-Sun Distance
    www.astro-tom.com/getting_started/earth-sun_distance.htm
National Science Education Standards
    www.nap.edu/html/nses/
U.S. Naval Observatory: Moon rise, set and altitude data
    aa.usno.navy.mil/data/
Voyage Online
    www.voyageonline.org

Acknowledgments

Activity 1 has been adapted from Activity 6.3, Building and Using a Pinhole Tube found in Project STAR The Universe in Your Hands, Kendall/Hunt Publishing Company, 1993, ISBN 0-8403-7715-0.

NOTES:

How Far is Far?

Lesson at a Glance

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Moon Visibility Tables

Teacher Answer Key

Moon Visibility Table
Fall / Winter 2005

The following table shows the dates and times when the Moon will be optimally visible in Washington, D.C., to perform Activity 2. The times for optimal visibility in the continental USA are similar (though they vary somewhat).

You can find the altitude of the Moon, as well as moonrise and moonset times for your exact location, at the U.S. Naval Observatory Astronomical Applications Department's Data Services web site: http://aa.usno.navy.mil/data/

The table show the date, rise time, and set time of the Moon when it is at least half full (no crescents), to make sure the Moon fills enough of the Moon-viewer cut-out to make the measurement accurate. Note that in most cases, the rise time is after the set time. This is because the Moon (when it is at least half full) is usually visible at midnight, and then it will set during the day, but rise again at night.

Date	Moon Rise	Moon Set
Mon, Sep 12	3:00 p.m.	11:55 p.m.
Tue, Sep 13	3:54 p.m.	
Wed, Sep 14	4:39 p.m.	1:09 a.m.
Thu, Sep 15	5:16 p.m.	2:28 a.m.
Fri, Sep 16	5:47 p.m.	3:48 a.m.
Sat, Sep 17	6:14 p.m.	5:05 a.m.
Sun, Sep 18	6:40 p.m.	6:21 a.m.
Mon, Sep 19	7:05 p.m.	7:34 a.m.
Tue, Sep 20	7:33 p.m.	8:47 a.m.
Wed, Sep 21	8:04 p.m.	9:59 a.m.
Thu, Sep 22	8:39 p.m.	11:10 a.m.
Fri, Sep 23	9:22 p.m.	12:17 p.m.
Sat, Sep 24	10:11 p.m.	1:18 p.m.
Sun, Sep 25	11:06 p.m.	2:11 p.m.
Tue, Oct 11	2:36 p.m.	
Wed, Oct 12	3:14 p.m.	12:10 a.m.
Thu, Oct 13	3:46 p.m.	1:27 a.m.
Fri, Oct 14	4:13 p.m.	2:43 a.m.
Sat, Oct 15	4:39 p.m.	3:57 a.m.
Sun, Oct 16	5:04 p.m.	5:10 a.m.
Mon, Oct 17	5:30 p.m.	6:22 a.m.
Tue, Oct 18	6:00 p.m.	7:35 a.m.
Wed, Oct 19	6:33 p.m.	8:48 a.m.
Thu, Oct 20	7:13 p.m.	9:58 a.m.
Fri, Oct 21	8:01 p.m.	11:04 a.m.
Sat, Oct 22	8:54 p.m.	12:02 p.m.
Sun, Oct 23	9:53 p.m.	12:51 p.m.
Mon, Oct 24	10:55 p.m.	1:31 p.m.
Wed, Nov 9	1:48 p.m.	
Thu, Nov 10	2:16 p.m.	12:29 a.m.
Fri, Nov 11	2:41 p.m.	1:42 a.m.
Sat, Nov 12	3:06 p.m.	2:53 a.m.
Sun, Nov 13	3:31 p.m.	4:03 a.m.
Mon, Nov 14	3:58 p.m.	5:14 a.m.
Tue, Nov 15	4:29 p.m.	6:26 a.m.
Wed, Nov 16	5:06 p.m.	7:37 a.m.
Thu, Nov 17	5:50 p.m.	8:46 a.m.
Fri, Nov 18	6:42 p.m.	9:48 a.m.
Sat, Nov 19	7:40 p.m.	10:42 a.m.

Sun, Nov 20	8:41 p.m.	11:26 a.m.
Mon, Nov 21	9:44 p.m.	12:03 p.m.
Tue, Nov 22	10:46 p.m.	12:33 p.m.
Wed, Nov 23	11:46 p.m.	12:58 p.m.
Fri, Dec 9	1:10 p.m.	12:44 a.m.
Sat, Dec 10	1:34 p.m.	1:53 a.m.
Sun, Dec 11	2:00 p.m.	3:02 a.m.
Mon, Dec 12	2:29 p.m.	4:12 a.m.
Tues, Dec 13	3:03 p.m.	5:22 a.m.
Wed, Dec 14	3:44 p.m.	6:30 a.m.
Thu, Dec 15	4:32 p.m.	7:35 a.m.
Fri, Dec 16	5:28 p.m.	8:32 a.m.
Sat, Dec 17	6:28 p.m.	9:20 a.m.
Sun, Dec 18	7:31 p.m.	10:00 a.m.
Mon, Dec 19	8:33 p.m.	10:32 a.m.
Tue, Dec 20	9:34 p.m.	10:59 a.m.
Wed, Dec 21	10:34 p.m.	11:22 a.m.
Thu, Dec 22	11:33 p.m.	11:44 a.m.
Fri, Dec 23		12:04 p.m.

Teaching Tip

Do not plan the activity for the last possible date shown in the table. If you do, it might be too cloudy to see the Moon, and there might not be any rain dates available.

Moon Visibility Table
2006

The following table shows the dates and times when the Moon will be optimally visible in Washington, D.C., to perform Activity 2. The times for optimal visibility in the continental USA are similar (though they vary somewhat).

You can find the altitude of the Moon, as well as moonrise and moonset times for your exact location, at the U.S. Naval Observatory Astronomical Applications Department's Data Services web site: http://aa.usno.navy.mil/data/

The table show the date, rise time, and set time of the Moon when it is at least half full (no crescents), to make sure the Moon fills enough of the Moon-viewer cut-out to make the measurement accurate. Note that in most cases, the rise time is after the set time. This is because the Moon (when it is at least half full) is usually visible at midnight, and then it will set during the day, but rise again at night.

Date	Moon Rise	Moon Set
Sat, Jan 7	12:03 p.m.	12:55 a.m.
Sun, Jan 8	12:31 p.m.	2:04 a.m.
Mon, Jan 9	1:03 p.m.	3:13 a.m.
Tue, Jan 10	1:41 p.m.	4:21 a.m.
Wed, Jan 11	2:26 p.m.	5:26 a.m.
Thu, Jan 12	3:19 p.m.	6:25 a.m.
Fri, Jan 13	4:18 p.m.	7:16 a.m.
Sat, Jan 14	5:20 p.m.	7:58 a.m.
Sun, Jan 15	6:23 p.m.	8:33 a.m.
Mon, Jan 16	7:24 p.m.	9:01 a.m.
Tue, Jan 17	8:24 p.m.	9:25 a.m.
Wed, Jan 18	9:23 p.m.	9:47 a.m.
Thu, Jan 19	10:22 p.m.	10:07 a.m.
Fri, Jan 20	11:21 p.m.	10:27 a.m.
Sat, Jan 21	12:00 a.m.	10:48 a.m.
Sun, Jan 22	12:22 a.m.	11:11 a.m.
Mon, Feb 6	11:40 a.m.	2:14 a.m.
Tue, Feb 7	12:23 p.m.	3:20 a.m.
Wed, Feb 8	1:14 p.m.	4:21 a.m.
Thu, Feb 9	2:11 p.m.	5:14 a.m.
Fri, Feb 10	3:12 p.m.	5:58 a.m.
Sat, Feb 11	4:14 p.m.	6:34 a.m.
Sun, Feb 12	5:16 p.m.	7:04 a.m.
Mon, Feb 13	6:17 p.m.	7:30 a.m.
Tue, Feb 14	7:16 p.m.	7:52 a.m.
Wed, Feb 15	8:15 p.m.	8:12 a.m.
Thu, Feb 16	9:13 p.m.	8:32 a.m.
Fri, Feb 17	10:13 p.m.	8:52 a.m.
Sat, Feb 18	11:16 p.m.	9:14 a.m.
Sun, Feb 19	12:00 a.m.	9:39 a.m.
Mon, Feb 20	12:21 a.m.	10:09 a.m.
Tue, Feb 21	1:29 a.m.	10:47 a.m.
Tue, Mar 7	11:08 a.m.	2:15 a.m.
Wed, Mar 8	12:04 p.m.	3:11 a.m.
Thu, Mar 9	1:04 p.m.	3:58 a.m.
Fri, Mar 10	2:06 p.m.	4:36 a.m.
Sat, Mar 11	3:08 p.m.	5:08 a.m.
Sun, Mar 12	4:09 p.m.	5:34 a.m.
Mon, Mar 13	5:09 p.m.	5:57 a.m.

Tue, Mar 14	6:08 p.m.	6:18 a.m.
Wed, Mar 15	7:07 p.m.	6:38 a.m.
Thu, Mar 16	8:07 p.m.	6:58 a.m.
Fri, Mar 17	9:08 p.m.	7:19 a.m.
Sat, Mar 18	10:13 p.m.	7:43 a.m.
Sun, Mar 19	11:19 p.m.	8:11 a.m.
Mon, Mar 20	12:00 a.m.	8:45 a.m.
Tue, Mar 21	12:27 a.m.	9:28 a.m.
Wed, Mar 22	1:32 a.m.	10:22 a.m.
Thu, Apr 6	11:56 a.m.	2:36 a.m.
Fri, Apr 7	12:59 p.m.	3:10 a.m.
Sat, Apr 8	2:01 p.m.	3:38 a.m.
Sun, Apr 9	3:01 p.m.	4:02 a.m.
Mon, Apr 10	4:00 p.m.	4:24 a.m.
Tue, Apr 11	4:59 p.m.	4:44 a.m.
Wed, Apr 12	5:59 p.m.	5:04 a.m.
Thu, Apr 13	7:00 p.m.	5:24 a.m.
Fri, Apr 14	8:04 p.m.	5:48 a.m.
Sat, Apr 15	9:11 p.m.	6:14 a.m.

Sun, Apr 16	10:19 p.m.	6:47 a.m.
Mon, Apr 17	11:25 p.m.	7:27 a.m.
Tue, Apr 18	12:00 a.m.	8:17 a.m.
Wed, Apr 19	12:25 a.m.	9:18 a.m.
Thu, Apr 20	1:18 a.m.	10:27 a.m.
Fri, May 5	11:50 a.m.	1:40 a.m.
Sat, May 6	12:51 p.m.	2:05 a.m.
Sun, May 7	1:50 p.m.	2:28 a.m.
Mon, May 8	2:49 p.m.	2:48 a.m.
Tue, May 9	3:48 p.m.	3:08 a.m.
Wed, May 10	4:49 p.m.	3:28 a.m.
Thu, May 11	5:52 p.m.	3:51 a.m.
Fri, May 12	6:59 p.m.	4:16 a.m.
Sat, May 13	8:07 p.m.	4:47 a.m.
Sun, May 14	9:15 p.m.	5:25 a.m.
Mon, May 15	10:19 p.m.	6:13 a.m.
Tue, May 16	11:15 p.m.	7:11 a.m.
Wed, May 17	12:00 a.m.	8:18 a.m.
Thu, May 18	12:01 a.m.	9:31 a.m.

Teaching Tip

Do not plan the activity for the last possible date shown in the table. If you do, it might be too cloudy to see the Moon, and there might not be any rain dates available.

Wed, Jun 7	3:38 p.m.	1:53 a.m.
Thu, Jun 8	4:43 p.m.	2:17 a.m.
Fri, Jun 9	5:51 p.m.	2:45 a.m.
Sat, Jun 10	7:00 p.m.	3:20 a.m.
Sun, Jun 11	8:07 p.m.	4:05 a.m.
Mon, Jun 12	9:07 p.m.	5:00 a.m.
Tue, Jun 13	9:58 p.m.	6:06 a.m.
Wed, Jun 14	10:40 p.m.	7:20 a.m.
Thu, Jun 15	11:13 p.m.	8:36 a.m.
Fri, Jun 16	11:42 p.m.	9:51 a.m.
Sat, Jun 17	12:00 a.m.	11:04 a.m.
Sun, Jun 18	12:08 a.m.	12:15 p.m.
Tue, Jul 4	1:24 p.m.	12:00 a.m.
Wed, Jul 5	2:27 p.m.	12:17 a.m.
Thu, Jul 6	3:33 p.m.	12:43 a.m.
Fri, Jul 7	4:41 p.m.	1:15 a.m.
Sat, Jul 8	5:49 p.m.	1:55 a.m.
Sun, Jul 9	6:53 p.m.	2:45 a.m.
Mon, Jul 10	7:49 p.m.	3:48 a.m.
Tue, Jul 11	8:35 p.m.	5:00 a.m.
Wed, Jul 12	9:13 p.m.	6:17 a.m.
Thu, Jul 13	9:44 p.m.	7:35 a.m.
Fri, Jul 14	10:11 p.m.	8:52 a.m.
Sat, Jul 15	10:36 p.m.	10:05 a.m.
Sun, Jul 16	11:01 p.m.	11:17 a.m.
Mon, Jul 17	11:28 p.m.	12:29 p.m.
Thu, Aug 3	2:23 p.m.	11:46 p.m.
Fri, Aug 4	3:30 p.m.	12:00 a.m.
Sat, Aug 5	4:36 p.m.	12:31 a.m.

Sun, Aug 6	5:35 p.m.	1:27 a.m.
Mon, Aug 7	6:26 p.m.	2:35 a.m.
Tue, Aug 8	7:07 p.m.	3:51 a.m.
Wed, Aug 9	7:42 p.m.	5:10 a.m.
Thu, Aug 10	8:11 p.m.	6:29 a.m.
Fri, Aug 11	8:38 p.m.	7:47 a.m.
Sat, Aug 12	9:03 p.m.	9:02 a.m.
Sun, Aug 13	9:30 p.m.	10:16 a.m.
Mon, Aug 14	9:59 p.m.	11:30 a.m.
Tue, Aug 15	10:33 p.m.	12:44 p.m.
Fri, Sep 1	2:20 p.m.	11:12 p.m.
Sat, Sep 2	3:21 p.m.	12:00 a.m.
Sun, Sep 3	4:14 p.m.	12:13 a.m.
Mon, Sep 4	4:59 p.m.	1:24 a.m.
Tue, Sep 5	5:36 p.m.	2:41 a.m.
Wed, Sep 6	6:08 p.m.	4:00 a.m.
Thu, Sep 7	6:36 p.m.	5:19 a.m.
Fri, Sep 8	7:02 p.m.	6:36 a.m.
Sat, Sep 9	7:29 p.m.	7:53 a.m.
Sun, Sep 10	7:58 p.m.	9:10 a.m.
Mon, Sep 11	8:31 p.m.	10:27 a.m.
Tue, Sep 12	9:10 p.m.	11:42 a.m.
Wed, Sep 13	9:56 p.m.	12:54 p.m.
Thu, Sep 14	10:50 p.m.	1:58 p.m.
Sun, Oct 1	2:52 p.m.	12:00 a.m.
Mon, Oct 2	3:31 p.m.	12:17 a.m.
Tue, Oct 3	4:04 p.m.	1:33 a.m.
Wed, Oct 4	4:33 p.m.	2:50 a.m.
Thu, Oct 5	5:00 p.m.	4:07 a.m.

Fri, Oct 6	5:27 p.m.	5:24 a.m.
Sat, Oct 7	5:55 p.m.	6:41 a.m.
Sun, Oct 8	6:26 p.m.	8:00 a.m.
Mon, Oct 9	7:03 p.m.	9:18 a.m.
Tue, Oct 10	7:48 p.m.	10:35 a.m.
Wed, Oct 11	8:41 p.m.	11:45 a.m.
Thu, Oct 12	9:41 p.m.	12:45 p.m.
Fri, Oct 13	10:45 p.m.	1:35 p.m.
Mon, Oct 30	2:03 p.m.	12:00 a.m.
Tue, Oct 31	2:32 p.m.	12:30 a.m.
Wed, Nov 1	2:59 p.m.	1:44 a.m.
Thu, Nov 2	3:25 p.m.	2:58 a.m.
Fri, Nov 3	3:51 p.m.	4:13 a.m.
Sat, Nov 4	4:21 p.m.	5:30 a.m.
Sun, Nov 5	4:55 p.m.	6:48 a.m.
Mon, Nov 6	5:36 p.m.	8:07 a.m.
Tue, Nov 7	6:26 p.m.	9:22 a.m.
Wed, Nov 8	7:25 p.m.	10:29 a.m.
Thu, Nov 9	8:30 p.m.	11:25 a.m.
Fri, Nov 10	9:36 p.m.	12:10 p.m.
Sat, Nov 11	10:42 p.m.	12:45 p.m.
Sun, Nov 12	11:45 p.m.	1:14 p.m.
Wed, Nov 29	1:26 p.m.	12:43 a.m.
Thu, Nov 30	1:51 p.m.	1:55 a.m.
Fri, Dec 1	2:18 p.m.	3:08 a.m.
Sat, Dec 2	2:49 p.m.	4:23 a.m.
Sun, Dec 3	3:26 p.m.	5:40 a.m.
Mon, Dec 4	4:12 p.m.	6:57 a.m.
Tue, Dec 5	5:07 p.m.	8:08 a.m.

Wed, Dec 6	6:10 p.m.	9:10 a.m.
Thu, Dec 7	7:17 p.m.	10:01 a.m.
Fri, Dec 8	8:25 p.m.	10:41 a.m.
Sat, Dec 9	9:31 p.m.	11:13 a.m.
Sun, Dec 10	10:33 p.m.	11:39 a.m.
Mon, Dec 11	11:33 p.m.	12:02 p.m.
Tue, Dec 12	12:00 a.m.	12:23 p.m.
Thu, Dec 28	12:20 p.m.	12:57 a.m.
Fri, Dec 29	12:49 p.m.	2:09 a.m.
Sat, Dec 30	1:22 p.m.	3:23 a.m.
Sun, Dec 31	2:03 p.m.	4:38 a.m.

Moon Visibility Table
2007

The following table shows the dates and times when the Moon will be optimally visible in Washington, D.C., to perform Activity 2. The times for optimal visibility in the continental USA are similar (though they vary somewhat).

You can find the altitude of the Moon, as well as moonrise and moonset times for your exact location, at the U.S. Naval Observatory Astronomical Applications Department's Data Services web site: http://aa.usno.navy.mil/data/

The table show the date, rise time, and set time of the Moon when it is at least half full (no crescents), to make sure the Moon fills enough of the Moon-viewer cut-out to make the measurement accurate. Note that in most cases, the rise time is after the set time. This is because the Moon (when it is at least half full) is usually visible at midnight, and then it will set during the day, but rise again at night.

Date	Moon Rise	Moon Set
Mon, Jan 1	2:53 p.m.	5:50 a.m.
Tue, Jan 2	3:52 p.m.	6:55 a.m.
Wed, Jan 3	4:58 p.m.	7:50 a.m.
Thu, Jan 4	6:06 p.m.	8:35 a.m.
Fri, Jan 5	7:14 p.m.	9:10 a.m.
Sat, Jan 6	8:18 p.m.	9:39 a.m.
Sun, Jan 7	9:20 p.m.	10:03 a.m.
Mon, Jan 8	10:19 p.m.	10:25 a.m.
Tue, Jan 9	11:18 p.m.	10:45 a.m.
Wed, Jan 10	12:00 a.m.	11:05 a.m.
Thu, Jan 11	12:16 a.m.	11:26 a.m.
Fri, Jan 26	11:23 a.m.	1:14 a.m.
Sat, Jan 27	12:01 p.m.	2:28 a.m.
Sun, Jan 28	12:47 p.m.	3:40 a.m.
Mon, Jan 29	1:42 p.m.	4:46 a.m.
Tue, Jan 30	2:44 p.m.	5:43 a.m.
Wed, Jan 31	3:51 p.m.	6:31 a.m.
Thu, Feb 1	4:58 p.m.	7:09 a.m.
Fri, Feb 2	6:04 p.m.	7:40 a.m.
Sat, Feb 3	7:07 p.m.	8:05 a.m.
Sun, Feb 4	8:08 p.m.	8:28 a.m.
Mon, Feb 5	9:07 p.m.	8:48 a.m.
Tue, Feb 6	10:05 p.m.	9:08 a.m.
Wed, Feb 7	11:04 p.m.	9:29 a.m.
Thu, Feb 8	12:00 a.m.	9:51 a.m.
Fri, Feb 9	12:05 a.m.	10:16 a.m.
Sat, Feb 10	1:08 a.m.	10:46 a.m.
Sun, Feb 25	11:36 a.m.	2:40 a.m.
Mon, Feb 26	12:36 p.m.	3:40 a.m.
Tue, Feb 27	1:41 p.m.	4:30 a.m.
Wed, Feb 28	2:48 p.m.	5:10 a.m.
Thu, Mar 1	3:53 p.m.	5:42 a.m.
Fri, Mar 2	4:57 p.m.	6:09 a.m.
Sat, Mar 3	5:58 p.m.	6:32 a.m.
Sun, Mar 4	6:57 p.m.	6:53 a.m.
Mon, Mar 5	7:56 p.m.	7:13 a.m.
Tue, Mar 6	8:55 p.m.	7:33 a.m.
Wed, Mar 7	9:55 p.m.	7:55 a.m.
Thu, Mar 8	10:56 p.m.	8:18 a.m.

Fri, Mar 9	11:59 p.m.	8:46 a.m.
Sat, Mar 10	12:00 a.m.	9:20 a.m.
Sun, Mar 11	1:02 a.m.	10:01 a.m.
Mon, Mar 12	2:02 a.m.	10:52 a.m.
Mon, Mar 26	11:33 a.m.	2:28 a.m.
Tue, Mar 27	12:40 p.m.	3:11 a.m.
Wed, Mar 28	1:46 p.m.	3:45 a.m.
Thu, Mar 29	2:49 p.m.	4:14 a.m.
Fri, Mar 30	3:50 p.m.	4:38 a.m.
Sat, Mar 31	4:50 p.m.	4:59 a.m.
Sun, Apr 1	5:48 p.m.	5:19 a.m.
Mon, Apr 2	6:47 p.m.	5:39 a.m.
Tue, Apr 3	7:47 p.m.	6:00 a.m.
Wed, Apr 4	8:48 p.m.	6:23 a.m.
Thu, Apr 5	9:50 p.m.	6:49 a.m.
Fri, Apr 6	10:53 p.m.	7:21 a.m.
Sat, Apr 7	11:53 p.m.	7:59 a.m.
Sun, Apr 8	12:00 a.m.	8:46 a.m.
Mon, Apr 9	12:49 a.m.	9:41 a.m.

Tue, Apr 10	1:39 a.m.	10:45 a.m.
Wed, Apr 25	12:42 p.m.	2:17 a.m.
Thu, Apr 26	1:44 p.m.	2:42 a.m.
Fri, Apr 27	2:44 p.m.	3:04 a.m.
Sat, Apr 28	3:42 p.m.	3:25 a.m.
Sun, Apr 29	4:40 p.m.	3:45 a.m.
Mon, Apr 30	5:40 p.m.	4:05 a.m.
Tue, May 1	6:40 p.m.	4:27 a.m.
Wed, May 2	7:42 p.m.	4:53 a.m.
Thu, May 3	8:45 p.m.	5:23 a.m.
Fri, May 4	9:47 p.m.	5:59 a.m.
Sat, May 5	10:44 p.m.	6:43 a.m.
Sun, May 6	11:35 p.m.	7:36 a.m.
Mon, May 7	12:00 a.m.	8:37 a.m.
Tue, May 8	12:19 a.m.	9:44 a.m.
Wed, May 9	12:56 a.m.	10:53 a.m.
Thu, May 10	1:27 a.m.	12:04 p.m.
Thu, May 24	12:35 p.m.	1:08 a.m.
Fri, May 25	1:35 p.m.	1:29 a.m.

TEACHING TIP

Do not plan the activity for the last possible date shown in the table. If you do, it might be too cloudy to see the Moon, and there might not be any rain dates .available.

Sat, May 26	2:33 p.m.	1:49 a.m.
Sun, May 27	3:32 p.m.	2:10 a.m.
Mon, May 28	4:32 p.m.	2:31 a.m.
Tue, May 29	5:33 p.m.	2:56 a.m.
Wed, May 30	6:36 p.m.	3:24 a.m.
Thu, May 31	7:39 p.m.	3:59 a.m.
Fri, Jun 1	8:38 p.m.	4:41 a.m.
Sat, Jun 2	9:32 p.m.	5:32 a.m.
Sun, Jun 3	10:18 p.m.	6:31 a.m.
Fri, Jun 16	11:42 p.m.	9:51 a.m.
Mon, Jun 4	10:57 p.m.	7:37 a.m.
Tue, Jun 5	11:30 p.m.	8:45 a.m.
Wed, Jun 6	11:58 p.m.	9:55 a.m.
Thu, Jun 7	12:00 a.m.	11:05 a.m.
Fri, Jun 8	12:24 a.m.	12:15 p.m.
Sat, Jun 23	1:22 p.m.	12:13 a.m.
Sun, Jun 24	2:22 p.m.	12:34 a.m.
Mon, Jun 25	3:23 p.m.	12:58 a.m.
Tue, Jun 26	4:25 p.m.	1:24 a.m.
Wed, Jun 27	5:28 p.m.	1:57 a.m.
Thu, Jun 28	6:29 p.m.	2:36 a.m.
Fri, Jun 29	7:26 p.m.	3:24 a.m.
Sat, Jun 30	8:15 p.m.	4:22 a.m.
Sun, Jul 1	8:57 p.m.	5:26 a.m.
Mon, Jul 2	9:32 p.m.	6:36 a.m.
Tue, Jul 3	10:01 p.m.	7:47 a.m.
Wed, Jul 4	10:28 p.m.	8:57 a.m.
Thu, Jul 5	10:52 p.m.	10:07 a.m.
Fri, Jul 6	11:17 p.m.	11:17 a.m.
Sat, Jul 7	11:43 p.m.	12:28 p.m.

Sun, Jul 22	1:10 p.m.	11:24 p.m.
Mon, Jul 23	2:12 p.m.	11:54 p.m.
Tue, Jul 24	3:15 p.m.	12:00 a.m.
Wed, Jul 25	4:17 p.m.	12:30 a.m.
Thu, Jul 26	5:15 p.m.	1:15 a.m.
Fri, Jul 27	6:08 p.m.	2:08 a.m.
Sat, Jul 28	6:53 p.m.	3:11 a.m.
Sun, Jul 29	7:31 p.m.	4:20 a.m.
Mon, Jul 30	8:03 p.m.	5:32 a.m.
Tue, Jul 31	8:31 p.m.	6:44 a.m.
Wed, Aug 1	8:56 p.m.	7:56 a.m.
Thu, Aug 2	9:21 p.m.	9:07 a.m.
Fri, Aug 3	9:47 p.m.	10:19 a.m.
Sat, Aug 4	10:16 p.m.	11:32 a.m.
Sun, Aug 5	10:49 p.m.	12:46 p.m.
Tue, Aug 21	2:03 p.m.	11:06 p.m.
Wed, Aug 22	3:03 p.m.	11:55 p.m.
Thu, Aug 23	3:58 p.m.	12:00 a.m.
Fri, Aug 24	4:45 p.m.	12:53 a.m.
Sat, Aug 25	5:26 p.m.	1:59 a.m.
Sun, Aug 26	6:01 p.m.	3:10 a.m.
Mon, Aug 27	6:31 p.m.	4:23 a.m.
Tue, Aug 28	6:58 p.m.	5:36 a.m.
Wed, Aug 29	7:23 p.m.	6:50 a.m.
Thu, Aug 30	7:50 p.m.	8:03 a.m.
Fri, Aug 31	8:18 p.m.	9:18 a.m.
Sat, Sep 1	8:50 p.m.	10:34 a.m.
Sun, Sep 2	9:29 p.m.	11:51 a.m.
Mon, Sep 3	10:16 p.m.	1:06 p.m.
Thu, Sep 20	2:37 p.m.	11:40 p.m.

Fri, Sep 21	3:20 p.m.	12:00 a.m.
Sat, Sep 22	3:56 p.m.	12:48 a.m.
Sun, Sep 23	4:28 p.m.	1:59 a.m.
Mon, Sep 24	4:56 p.m.	3:11 a.m.
Tue, Sep 25	5:22 p.m.	4:25 a.m.
Wed, Sep 26	5:49 p.m.	5:39 a.m.
Thu, Sep 27	6:17 p.m.	6:55 a.m.
Fri, Sep 28	6:48 p.m.	8:13 a.m.
Sat, Sep 29	7:26 p.m.	9:32 a.m.
Sun, Sep 30	8:11 p.m.	10:51 a.m.
Mon, Oct 1	9:06 p.m.	12:04 p.m.
Tue, Oct 2	10:09 p.m.	1:08 p.m.
Wed, Oct 3	11:17 p.m.	2:01 p.m.
Sat, Oct 20	2:25 p.m.	12:00 a.m.
Sun, Oct 21	2:54 p.m.	12:49 a.m.
Mon, Oct 22	3:20 p.m.	2:00 a.m.
Tue, Oct 23	3:46 p.m.	3:12 a.m.
Tue, Oct 23	3:46 p.m.	3:12 a.m.
Wed, Oct 24	4:13 p.m.	4:26 a.m.
Thu, Oct 25	4:43 p.m.	5:43 a.m.
Fri, Oct 26	5:18 p.m.	7:03 a.m.
Sat, Oct 27	6:01 p.m.	8:24 a.m.
Sun, Oct 28	6:53 p.m.	9:43 a.m.
Mon, Oct 29	7:56 p.m.	10:54 a.m.
Tue, Oct 30	9:05 p.m.	11:54 a.m.
Wed, Oct 31	10:15 p.m.	12:41 p.m.
Thu, Nov 1	11:25 p.m.	1:18 p.m.
Sun, Nov 18	1:20 p.m.	12:00 a.m.
Mon, Nov 19	1:45 p.m.	12:52 a.m.
Tue, Nov 20	2:10 p.m.	2:02 a.m.

Wed, Nov 21	2:38 p.m.	3:14 a.m.
Thu, Nov 22	3:09 p.m.	4:31 a.m.
Fri, Nov 23	3:48 p.m.	5:51 a.m.
Sat, Nov 24	4:36 p.m.	7:12 a.m.
Sun, Nov 25	5:35 p.m.	8:29 a.m.
Mon, Nov 26	6:43 p.m.	9:37 a.m.
Tue, Nov 27	7:57 p.m.	10:31 a.m.
Wed, Nov 28	9:09 p.m.	11:14 a.m.
Thu, Nov 29	10:19 p.m.	11:47 a.m.
Fri, Nov 30	11:24 p.m.	12:15 p.m.
Sat, Dec 1	12:00 a.m.	12:38 p.m.
Tue, Dec 18	12:37 p.m.	12:57 a.m.
Wed, Dec 19	1:05 p.m.	2:09 a.m.
Thu, Dec 20	1:39 p.m.	3:25 a.m.
Fri, Dec 21	2:21 p.m.	4:43 a.m.
Sat, Dec 22	3:14 p.m.	6:01 a.m.
Sun, Dec 23	4:17 p.m.	7:13 a.m.
Mon, Dec 24	5:30 p.m.	8:15 a.m.
Tue, Dec 25	6:45 p.m.	9:04 a.m.
Wed, Dec 26	7:58 p.m.	9:42 a.m.
Thu, Dec 27	9:08 p.m.	10:13 a.m.
Fri, Dec 28	10:13 p.m.	10:39 a.m.
Sat, Dec 29	11:15 p.m.	11:02 a.m.
Sun, Dec 30	12:00 a.m.	11:23 a.m.
Mon, Dec 31	12:15 a.m.	11:45 a.m.

Moon Visibility Table
2008

The following table shows the dates and times when the Moon will be optimally visible in Washington, D.C., to perform Activity 2. The times for optimal visibility in the continental USA are similar (though they vary somewhat).

You can find the altitude of the Moon, as well as moonrise and moonset times for your exact location, at the U.S. Naval Observatory Astronomical Applications Department's Data Services web site: http://aa.usno.navy.mil/data/

The table show the date, rise time, and set time of the Moon when it is at least half full (no crescents), to make sure the Moon fills enough of the Moon-viewer cut-out to make the measurement accurate. Note that in most cases, the rise time is after the set time. This is because the Moon (when it is at least half full) is usually visible at midnight, and then it will set during the day, but rise again at night.

Date	Moon Rise	Moon Set
Wed, Jan 16	11:37 a.m.	1:11 a.m.
Thu, Jan 17	12:14 p.m.	2:25 a.m.
Fri, Jan 18	1:01 p.m.	3:41 a.m.
Sat, Jan 19	1:58 p.m.	4:54 a.m.
Sun, Jan 20	3:05 p.m.	5:59 a.m.
Mon, Jan 21	4:18 p.m.	6:52 a.m.
Tue, Jan 22	5:33 p.m.	7:35 a.m.
Wed, Jan 23	6:45 p.m.	8:10 a.m.
Thu, Jan 24	7:54 p.m.	8:38 a.m.
Fri, Jan 25	8:59 p.m.	9:03 a.m.
Sat, Jan 26	10:01 p.m.	9:25 a.m.
Sun, Jan 27	11:02 p.m.	9:47 a.m.
Mon, Jan 28	12:00 a.m.	10:09 a.m.
Tue, Jan 29	12:03 a.m.	10:34 a.m.
Wed, Jan 30	1:04 a.m.	11:01 a.m.
Thu, Feb 14	10:57 a.m.	1:31 a.m.
Fri, Feb 15	11:49 a.m.	2:43 a.m.
Sat, Feb 16	12:51 p.m.	3:49 a.m.
Sun, Feb 17	2:00 p.m.	4:45 a.m.
Mon, Feb 18	3:13 p.m.	5:31 a.m.
Tue, Feb 19	4:25 p.m.	6:08 a.m.
Wed, Feb 20	5:35 p.m.	6:38 a.m.
Thu, Feb 21	6:41 p.m.	7:04 a.m.
Fri, Feb 22	7:45 p.m.	7:27 a.m.
Sat, Feb 23	8:47 p.m.	7:49 a.m.
Sun, Feb 24	9:49 p.m.	8:11 a.m.
Mon, Feb 25	10:51 p.m.	8:35 a.m.
Tue, Feb 26	11:52 p.m.	9:01 a.m.
Wed, Feb 27	12:00 a.m.	9:32 a.m.
Thu, Feb 28	12:54 a.m.	10:08 a.m.
Sat, Mar 15	11:51 a.m.	2:42 a.m.
Sun, Mar 16	1:02 p.m.	3:30 a.m.
Mon, Mar 17	2:13 p.m.	4:08 a.m.
Tue, Mar 18	3:22 p.m.	4:40 a.m.
Wed, Mar 19	4:28 p.m.	5:06 a.m.
Thu, Mar 20	5:31 p.m.	5:30 a.m.
Fri, Mar 21	6:34 p.m.	5:52 a.m.
Sat, Mar 22	7:36 p.m.	6:14 a.m.
Sun, Mar 23	8:37 p.m.	6:37 a.m.

Mon, Mar 24	9:39 p.m.	7:03 a.m.
Tue, Mar 25	10:41 p.m.	7:32 a.m.
Wed, Mar 26	11:41 p.m.	8:06 a.m.
Thu, Mar 27	12:00 a.m.	8:46 a.m.
Fri, Mar 28	12:38 a.m.	9:34 a.m.
Tue, Mar 27	12:40 p.m.	3:11 a.m.
Mon, Mar 24	9:39 p.m.	7:03 a.m.
Tue, Mar 25	10:41 p.m.	7:32 a.m.
Wed, Mar 26	11:41 p.m.	8:06 a.m.
Thu, Mar 27	12:00 a.m.	8:46 a.m.
Fri, Mar 28	12:38 a.m.	9:34 a.m.
Thu, Apr 17	4:25 p.m.	3:57 a.m.
Fri, Apr 18	5:26 p.m.	4:19 a.m.
Sat, Apr 19	6:27 p.m.	4:42 a.m.
Sun, Apr 20	7:29 p.m.	5:06 a.m.
Mon, Apr 21	8:31 p.m.	5:34 a.m.
Tue, Apr 22	9:32 p.m.	6:06 a.m.
Wed, Apr 23	10:29 p.m.	6:44 a.m.
Thu, Apr 24	11:22 p.m.	7:29 a.m.

Fri, Apr 25	12:00 a.m.	8:21 a.m.
Sat, Apr 26	12:09 a.m.	9:19 a.m.
Sun, Apr 27	12:49 a.m.	10:21 a.m.
Mon, Apr 28	1:23 a.m.	11:25 a.m.
Mon, May 12	12:13 p.m.	1:14 a.m.
Tue, May 13	1:17 p.m.	1:39 a.m.
Wed, May 14	2:19 p.m.	2:02 a.m.
Thu, May 15	3:20 p.m.	2:24 a.m.
Fri, May 16	4:21 p.m.	2:46 a.m.
Sat, May 17	5:22 p.m.	3:10 a.m.
Sun, May 18	6:23 p.m.	3:37 a.m.
Mon, May 19	7:24 p.m.	4:07 a.m.
Tue, May 20	8:23 p.m.	4:43 a.m.
Wed, May 21	9:17 p.m.	5:26 a.m.
Thu, May 22	10:06 p.m.	6:16 a.m.
Fri, May 23	10:48 p.m.	7:12 a.m.
Sat, May 24	11:23 p.m.	8:13 a.m.
Sun, May 25	11:54 p.m.	9:16 a.m.
Mon, May 26	12:00 a.m.	10:20 a.m.

TEACHING TIP

Do not plan the activity for the last possible date shown in the table. If you do, it might be too cloudy to see the Moon, and there might not be any rain dates available.

Tue, May 27	12:21 a.m.	11:25 a.m.
Wed, Jun 11	1:13 p.m.	12:28 a.m.
Thu, Jun 12	2:14 p.m.	12:51 a.m.
Fri, Jun 13	3:15 p.m.	1:14 a.m.
Sat, Jun 14	4:16 p.m.	1:40 a.m.
Sun, Jun 15	5:17 p.m.	2:09 a.m.
Mon, Jun 16	6:17 p.m.	2:43 a.m.
Tue, Jun 17	7:13 p.m.	3:24 a.m.
Wed, Jun 18	8:03 p.m.	4:12 a.m.
Thu, Jun 19	8:47 p.m.	5:07 a.m.
Fri, Jun 20	9:25 p.m.	6:06 a.m.
Sat, Jun 21	9:57 p.m.	7:09 a.m.
Sun, Jun 22	10:24 p.m.	8:13 a.m.
Mon, Jun 23	10:49 p.m.	9:17 a.m.
Tue, Jun 24	11:13 p.m.	10:21 a.m.
Wed, Jun 25	11:37 p.m.	11:26 a.m.
Thu, Jun 26	12:00 a.m.	12:33 p.m.
Thu, Jul 10	1:06 p.m.	11:42 p.m.
Fri, Jul 11	2:07 p.m.	12:00 a.m.
Sat, Jul 12	3:09 p.m.	12:10 a.m.
Sun, Jul 13	4:09 p.m.	12:42 a.m.
Wed, Jul 16	6:46 p.m.	2:59 a.m.
Thu, Jul 17	7:25 p.m.	3:58 a.m.
Fri, Jul 18	7:59 p.m.	5:01 a.m.
Sat, Jul 19	8:28 p.m.	6:05 a.m.
Sun, Jul 20	8:54 p.m.	7:10 a.m.
Mon, Jul 21	9:18 p.m.	8:14 a.m.
Tue, Jul 22	9:42 p.m.	9:19 a.m.
Wed, Jul 23	10:06 p.m.	10:25 a.m.

Thu, Jul 24	10:33 p.m.	11:33 a.m.
Fri, Jul 25	11:05 p.m.	12:44 p.m.
Sat, Aug 9	1:59 p.m.	11:18 p.m.
Sun, Aug 10	2:58 p.m.	12:00 a.m.
Mon, Aug 11	3:53 p.m.	12:01 a.m.
Tue, Aug 12	4:41 p.m.	12:51 a.m.
Wed, Aug 13	5:23 p.m.	1:47 a.m.
Thu, Aug 14	5:59 p.m.	2:49 a.m.
Fri, Aug 15	6:30 p.m.	3:53 a.m.
Sat, Aug 16	6:58 p.m.	4:59 a.m.
Sun, Aug 17	7:22 p.m.	6:04 a.m.
Mon, Aug 18	7:46 p.m.	7:10 a.m.
Tue, Aug 19	8:11 p.m.	8:17 a.m.
Wed, Aug 20	8:37 p.m.	9:25 a.m.
Thu, Aug 21	9:07 p.m.	10:35 a.m.
Fri, Aug 22	9:43 p.m.	11:48 a.m.
Sat, Aug 23	10:27 p.m.	1:02 p.m.
Mon, Sep 8	2:34 p.m.	11:36 p.m.
Tue, Sep 9	3:19 p.m.	12:00 a.m.
Wed, Sep 10	3:57 p.m.	12:35 a.m.
Thu, Sep 11	4:30 p.m.	1:38 a.m.
Fri, Sep 12	4:58 p.m.	2:43 a.m.
Sat, Sep 13	5:24 p.m.	3:49 a.m.
Sun, Sep 14	5:49 p.m.	4:55 a.m.
Tue, Sep 16	6:40 p.m.	7:11 a.m.
Wed, Sep 17	7:09 p.m.	8:23 a.m.
Thu, Sep 18	7:44 p.m.	9:36 a.m.
Fri, Sep 19	8:26 p.m.	10:51 a.m.
Sat, Sep 20	9:17 p.m.	12:04 p.m.

Sun, Sep 21	10:18 p.m.	1:11 p.m.
Mon, Sep 22	11:27 p.m.	2:09 p.m.
Wed, Oct 8	2:27 p.m.	12:00 a.m.
Thu, Oct 9	2:57 p.m.	12:26 a.m.
Fri, Oct 10	3:24 p.m.	1:31 a.m.
Sat, Oct 11	3:49 p.m.	2:36 a.m.
Sun, Oct 12	4:14 p.m.	3:42 a.m.
Mon, Oct 13	4:40 p.m.	4:51 a.m.
Tue, Oct 14	5:08 p.m.	6:02 a.m.
Wed, Oct 15	5:41 p.m.	7:16 a.m.
Thu, Oct 16	6:22 p.m.	8:33 a.m.
Fri, Oct 17	7:11 p.m.	9:50 a.m.
Sat, Oct 18	8:11 p.m.	11:01 a.m.
Sun, Oct 19	9:19 p.m.	12:04 p.m.
Mon, Oct 20	10:31 p.m.	12:55 p.m.
Tue, Oct 21	11:44 p.m.	1:36 p.m.
Thu, Nov 6	1:23 p.m.	12:00 a.m.
Fri, Nov 7	1:48 p.m.	12:19 a.m.
Sun, Nov 16	8:17 p.m.	10:47 a.m.
Mon, Nov 17	9:33 p.m.	11:33 a.m.
Tue, Nov 18	10:45 p.m.	12:10 p.m.
Wed, Nov 19	11:54 p.m.	12:40 p.m.
Sat, Dec 6	12:37 p.m.	12:12 a.m.
Sun, Dec 7	1:02 p.m.	1:17 a.m.
Mon, Dec 8	1:30 p.m.	2:25 a.m.
Tue, Dec 9	2:03 p.m.	3:37 a.m.
Wed, Dec 10	2:44 p.m.	4:53 a.m.
Thu, Dec 11	3:35 p.m.	6:11 a.m.
Fri, Dec 12	4:39 p.m.	7:25 a.m.

Sat, Dec 13	5:52 p.m.	8:30 a.m.
Sun, Dec 14	7:10 p.m.	9:23 a.m.
Mon, Dec 15	8:27 p.m.	10:06 a.m.
Tue, Dec 16	9:41 p.m.	10:40 a.m.
Wed, Dec 17	10:50 p.m.	11:08 a.m.
Thu, Dec 18	11:56 p.m.	11:34 a.m.
Fri, Dec 19	12:00 a.m.	11:58 a.m.

Moon Visibility Table
2009

The following table shows the dates and times when the Moon will be optimally visible in Washington, D.C., to perform Activity 2. The times for optimal visibility in the continental USA are similar (though they vary somewhat).

You can find the altitude of the Moon, as well as moonrise and moonset times for your exact location, at the U.S. Naval Observatory Astronomical Applications Department's Data Services web site: http://aa.usno.navy.mil/data/

The table show the date, rise time, and set time of the Moon when it is at least half full (no crescents), to make sure the Moon fills enough of the Moon-viewer cut-out to make the measurement accurate. Note that in most cases, the rise time is after the set time. This is because the Moon (when it is at least half full) is usually visible at midnight, and then it will set during the day, but rise again at night.

Date	Moon Rise	Moon Set
Mon, Jan 5	11:58 a.m.	1:18 a.m.
Tue, Jan 6	12:34 p.m.	2:30 a.m.
Wed, Jan 7	1:18 p.m.	3:44 a.m.
Thu, Jan 8	2:14 p.m.	4:58 a.m.
Fri, Jan 9	3:22 p.m.	6:08 a.m.
Sat, Jan 10	4:38 p.m.	7:07 a.m.
Sun, Jan 11	5:58 p.m.	7:55 a.m.
Mon, Jan 12	7:15 p.m.	8:34 a.m.
Tue, Jan 13	8:29 p.m.	9:06 a.m.
Wed, Jan 14	9:39 p.m.	9:34 a.m.
Thu, Jan 15	10:46 p.m.	9:59 a.m.
Fri, Jan 16	11:51 p.m.	10:24 a.m.
Sat, Jan 17	12:00 a.m.	10:50 a.m.
Tue, Feb 3	11:11 a.m.	1:28 a.m.
Wed, Feb 4	12:00 p.m.	2:40 a.m.
Thu, Feb 5	1:00 p.m.	3:49 a.m.
Fri, Feb 6	2:10 p.m.	4:51 a.m.
Sat, Feb 7	3:27 p.m.	5:43 a.m.
Sun, Feb 8	4:45 p.m.	6:26 a.m.
Mon, Feb 9	6:02 p.m.	7:01 a.m.
Tue, Feb 10	7:15 p.m.	7:31 a.m.
Wed, Feb 11	8:25 p.m.	7:58 a.m.
Thu, Feb 12	9:33 p.m.	8:24 a.m.
Fri, Feb 13	10:39 p.m.	8:50 a.m.
Sat, Feb 14	11:44 p.m.	9:17 a.m.
Sun, Feb 15	12:00 a.m.	9:48 a.m.
Mon, Feb 16	12:48 a.m.	10:23 a.m.
Thu, Mar 5	11:56 a.m.	2:42 a.m.
Fri, Mar 6	1:08 p.m.	3:36 a.m.
Sat, Mar 7	2:23 p.m.	4:20 a.m.
Sun, Mar 8	3:38 p.m.	4:57 a.m.
Mon, Mar 9	4:51 p.m.	5:29 a.m.
Tue, Mar 10	6:02 p.m.	5:57 a.m.
Wed, Mar 11	7:11 p.m.	6:23 a.m.
Thu, Mar 12	8:19 p.m.	6:49 a.m.
Fri, Mar 13	9:26 p.m.	7:16 a.m.
Sat, Mar 14	10:31 p.m.	7:46 a.m.
Sun, Mar 15	11:35 p.m.	8:19 a.m.
Mon, Mar 16	12:00 a.m.	8:58 a.m.

Tue, Mar 17	12:35 a.m.	9:43 a.m.
Wed, Mar 18	1:29 a.m.	10:33 a.m.
Fri, Apr 3	12:11 p.m.	2:19 a.m.
Sat, Apr 4	1:24 p.m.	2:57 a.m.
Sun, Apr 5	2:36 p.m.	3:30 a.m.
Mon, Apr 6	3:46 p.m.	3:58 a.m.
Tue, Apr 7	4:54 p.m.	4:24 a.m.
Wed, Apr 8	6:01 p.m.	4:50 a.m.
Thu, Apr 9	7:08 p.m.	5:16 a.m.
Fri, Apr 10	8:14 p.m.	5:45 a.m.
Sat, Apr 11	9:19 p.m.	6:17 a.m.
Sun, Apr 12	10:21 p.m.	6:53 a.m.
Mon, Apr 13	11:18 p.m.	7:36 a.m.
Tue, Apr 14	12:00 a.m.	8:25 a.m.
Wed, Apr 15	12:08 a.m.	9:19 a.m.
Thu, Apr 16	12:52 a.m.	10:17 a.m.
Fri, Apr 17	1:29 a.m.	11:17 a.m.
Sat, May 2	12:28 p.m.	1:32 a.m.
Sun, May 3	1:37 p.m.	2:01 a.m.

Mon, May 4	2:44 p.m.	2:28 a.m.
Tue, May 5	3:50 p.m.	2:53 a.m.
Wed, May 6	4:55 p.m.	3:18 a.m.
Thu, May 7	6:01 p.m.	3:46 a.m.
Fri, May 8	7:06 p.m.	4:16 a.m.
Sat, May 9	8:09 p.m.	4:51 a.m.
Sun, May 10	9:08 p.m.	5:31 a.m.
Mon, May 11	10:01 p.m.	6:18 a.m.
Tue, May 12	10:47 p.m.	7:10 a.m.
Wed, May 13	11:26 p.m.	8:07 a.m.
Thu, May 14	11:59 p.m.	9:06 a.m.
Fri, May 15	12:00 a.m.	10:07 a.m.
Sat, May 16	12:28 a.m.	11:07 a.m.
Sun, May 17	12:54 a.m.	12:08 p.m.
Sun, May 31	12:37 p.m.	12:31 a.m.
Mon, Jun 1	1:43 p.m.	12:57 a.m.
Tue, Jun 2	2:48 p.m.	1:22 a.m.
Wed, Jun 3	3:53 p.m.	1:49 a.m.
Thu, Jun 4	4:57 p.m.	2:18 a.m.

Teaching Tip

Do not plan the activity for the last possible date shown in the table. If you do, it might be too cloudy to see the Moon, and there might not be any rain dates available.

Fri, Jun 5	6:00 p.m.	2:51 a.m.
Sat, Jun 6	7:00 p.m.	3:29 a.m.
Sun, Jun 7	7:55 p.m.	4:13 a.m.
Mon, Jun 8	8:43 p.m.	5:04 a.m.
Tue, Jun 9	9:24 p.m.	5:59 a.m.
Wed, Jun 10	10:00 p.m.	6:58 a.m.
Thu, Jun 11	10:30 p.m.	7:58 a.m.
Fri, Jun 12	10:56 p.m.	8:58 a.m.
Sat, Jun 13	11:20 p.m.	9:58 a.m.
Sun, Jun 14	11:43 p.m.	10:57 a.m.
Mon, Jun 15	12:00 a.m.	11:58 a.m.
Tue, Jun 30	1:45 p.m.	12:00 a.m.
Wed, Jul 1	2:50 p.m.	12:20 a.m.
Thu, Jul 2	3:53 p.m.	12:52 a.m.
Fri, Jul 3	4:54 p.m.	1:28 a.m.
Sat, Jul 4	5:50 p.m.	2:10 a.m.
Sun, Jul 5	6:40 p.m.	2:59 a.m.
Mon, Jul 6	7:24 p.m.	3:53 a.m.
Tue, Jul 7	8:01 p.m.	4:51 a.m.
Wed, Jul 8	8:32 p.m.	5:51 a.m.
Thu, Jul 9	9:00 p.m.	6:51 a.m.
Fri, Jul 10	9:25 p.m.	7:51 a.m.
Sat, Jul 11	9:48 p.m.	8:50 a.m.
Sun, Jul 12	10:10 p.m.	9:50 a.m.
Mon, Jul 13	10:34 p.m.	10:50 a.m.
Tue, Jul 14	11:00 p.m.	11:53 a.m.
Wed, Jul 15	11:30 p.m.	12:59 p.m.
Wed, Jul 29	1:45 p.m.	11:28 p.m.
Thu, Jul 30	2:47 p.m.	12:00 a.m.

Fri, Jul 31	3:45 p.m.	12:09 a.m.
Sat, Aug 1	4:37 p.m.	12:55 a.m.
Sun, Aug 2	5:23 p.m.	1:47 a.m.
Mon, Aug 3	6:02 p.m.	2:44 a.m.
Tue, Aug 4	6:35 p.m.	3:43 a.m.
Wed, Aug 5	7:04 p.m.	4:44 a.m.
Thu, Aug 6	7:30 p.m.	5:44 a.m.
Fri, Aug 7	7:53 p.m.	6:44 a.m.
Sat, Aug 8	8:16 p.m.	7:44 a.m.
Sun, Aug 9	8:39 p.m.	8:44 a.m.
Mon, Aug 10	9:04 p.m.	9:45 a.m.
Tue, Aug 11	9:32 p.m.	10:49 a.m.
Wed, Aug 12	10:05 p.m.	11:55 a.m.
Thu, Aug 13	10:45 p.m.	1:04 p.m.
Fri, Aug 28	2:32 p.m.	11:41 p.m.
Sat, Aug 29	3:20 p.m.	12:00 a.m.
Sun, Aug 30	4:01 p.m.	12:36 a.m.
Mon, Aug 31	4:36 p.m.	1:35 a.m.
Tue, Sep 1	5:07 p.m.	2:35 a.m.
Wed, Sep 2	5:33 p.m.	3:36 a.m.
Thu, Sep 3	5:58 p.m.	4:36 a.m.
Fri, Sep 4	6:21 p.m.	5:36 a.m.
Sat, Sep 5	6:45 p.m.	6:37 a.m.
Sun, Sep 6	7:09 p.m.	7:38 a.m.
Mon, Sep 7	7:36 p.m.	8:42 a.m.
Tue, Sep 8	8:08 p.m.	9:48 a.m.
Wed, Sep 9	8:45 p.m.	10:55 a.m.
Thu, Sep 10	9:31 p.m.	12:03 p.m.
Fri, Sep 11	10:26 p.m.	1:09 p.m.

Sat, Sep 26	1:58 p.m.	11:25 p.m.
Sun, Sep 27	2:35 p.m.	12:00 a.m.
Mon, Sep 28	3:07 p.m.	12:25 a.m.
Tue, Sep 29	3:35 p.m.	1:25 a.m.
Wed, Sep 30	4:01 p.m.	2:25 a.m.
Thu, Oct 1	4:24 p.m.	3:25 a.m.
Fri, Oct 2	4:48 p.m.	4:26 a.m.
Sat, Oct 3	5:13 p.m.	5:28 a.m.
Sun, Oct 4	5:39 p.m.	6:31 a.m.
Mon, Oct 5	6:10 p.m.	7:37 a.m.
Tue, Oct 6	6:46 p.m.	8:46 a.m.
Wed, Oct 7	7:30 p.m.	9:55 a.m.
Thu, Oct 8	8:22 p.m.	11:02 a.m.
Fri, Oct 9	9:24 p.m.	12:03 p.m.
Sat, Oct 10	10:33 p.m.	12:57 p.m.
Sun, Oct 11	11:45 p.m.	1:43 p.m.
Mon, Oct 26	1:35 p.m.	12:00 a.m.
Tue, Oct 27	2:01 p.m.	12:13 a.m.
Wed, Oct 28	2:26 p.m.	1:12 a.m.
Thu, Oct 29	2:49 p.m.	2:12 a.m.
Fri, Oct 30	3:13 p.m.	3:13 a.m.
Sat, Oct 31	3:39 p.m.	4:16 a.m.
Sun, Nov 1	4:09 p.m.	5:21 a.m.
Mon, Nov 2	4:43 p.m.	6:30 a.m.
Tue, Nov 3	5:25 p.m.	7:40 a.m.
Wed, Nov 4	6:16 p.m.	8:50 a.m.
Thu, Nov 5	7:17 p.m.	9:55 a.m.
Fri, Nov 6	8:25 p.m.	10:53 a.m.
Sat, Nov 7	9:37 p.m.	11:42 a.m.

Sun, Nov 8	10:50 p.m.	12:22 p.m.
Mon, Nov 9	12:00 a.m.	12:56 p.m.
Wed, Nov 25	12:50 p.m.	12:00 a.m.
Thu, Nov 26	1:13 p.m.	12:58 a.m.
Fri, Nov 27	1:38 p.m.	1:59 a.m.
Sat, Nov 28	2:05 p.m.	3:02 a.m.
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Mon, Dec 28	1:49 p.m.	4:04 a.m.
Tue, Dec 29	2:41 p.m.	5:14 a.m.
Wed, Dec 30	3:44 p.m.	6:21 a.m.
Thu, Dec 31	4:57 p.m.	7:20 a.m.

Teacher Answer Key

Student Worksheet 1

Part III

1. Answers will vary depending on the length of the tube. Most tubes are 28 cm (280 mm), yielding an image size of 2.6 millimeters.

2. Answers will vary depending on the length of the tube. Most tubes are 28 cm (280 mm).

3. Tube length/ image width = 280 mm/ 2.6 mm = 107*

5. See Data Table below.

6. 107*, or the same number you calculated in Question 3.

* The number of Suns that could fit between the Earth and the Sun actually varies from 106-109 during the year, due to the fact that the Earth's orbit is not a perfect circle.

Table	Little Triangle	Big Triangle
Where is the point of the triangle?	At the pinhole.	At the pinhole.
What forms the base of the triangle?	The diameter of the model Sun.	The diameter of the real Sun.
What is the length of the triangle?	The length of the tube.	The distance between the real Sun and the real Earth.
How many bases fit along the length of the triangle?	About 107.	About 107.
What did you figure out?	The number of model Suns that fit along the length of the tube.	The number of real Suns that fit between the real Earth and the real Sun.
What did you use as a ruler?	The model Sun.	The real Sun.

Questions

1. The image is not a very detailed model of the Sun, so it limits what we can learn about the Sun. Nevertheless, it is all we need to find the distance to the Sun.

2. 

3. The Earth does not orbit the Sun in a perfect circle, so the Sun-Earth distance changes slightly.

4. $\frac{\text{Your Shadow (2')}}{\text{Your Height (4')}}$ = 0.5; 0.5 x Height of Flagpole (12′) = 6′

   So the flagpole's shadow is 6′.

5. 1,400,000 x 107 (or answer to Part III, Question 5) = 150,000,000 km

6. Answers will vary.

Student Worksheet 2

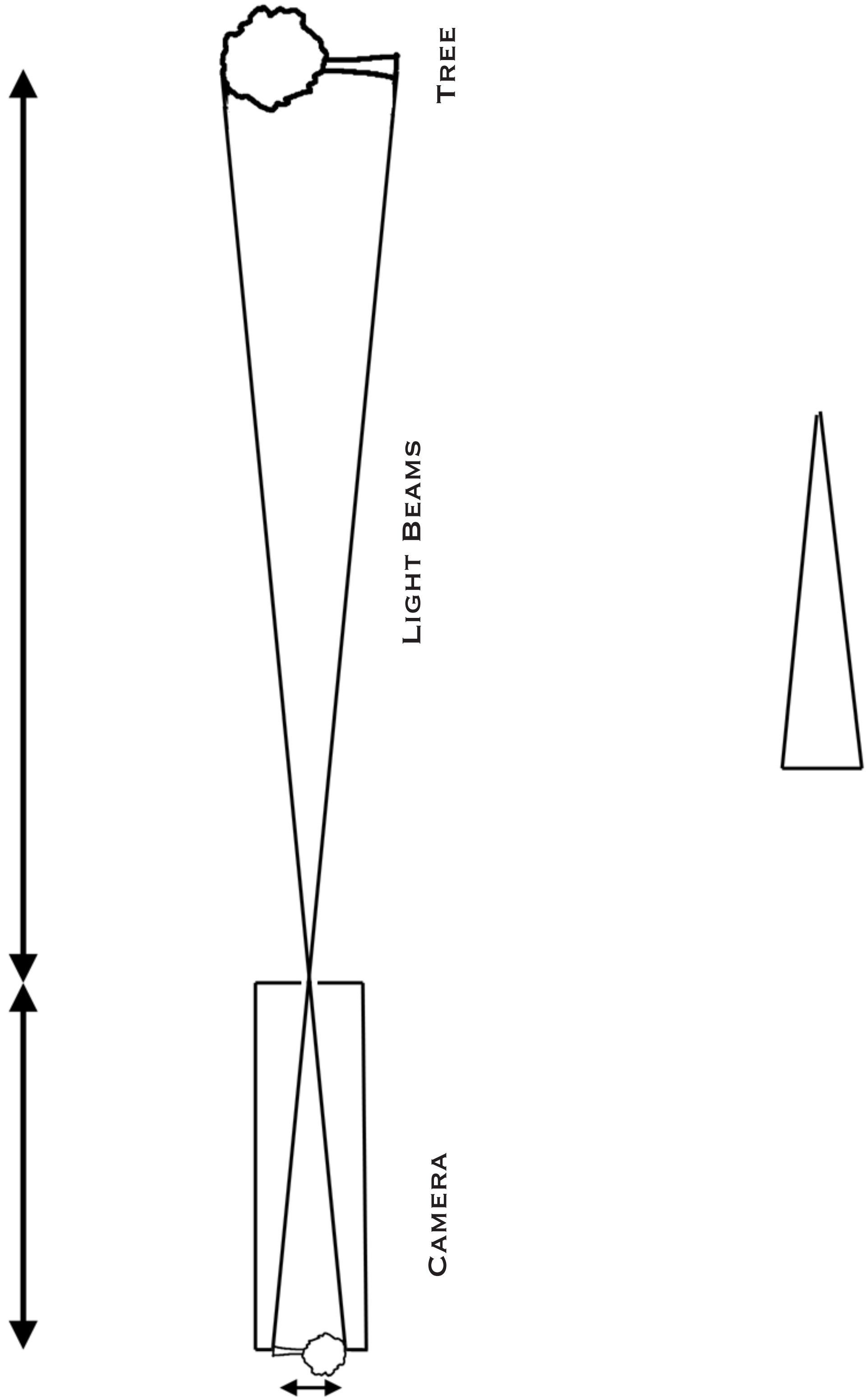
Data Table

Table	Little Triangle	Big Triangle
Where is the point of the triangle?	At my eye.	At my eye..
What forms the base of the triangle?	The diameter of the Moon-viewer cut-out (2 cm).	The diameter of the real Moon.
What is the length of the triangle?	The distance between my eye and the Moon-viewer.	The distance between the real Earth and the real Moon.
How many bases fit along the length of the triangle?	About 107 (length of string / 2 cm).	About 107.
What did you figure out?	The number of model Moons that would fit along the length of the string.	The number of real Moons that fit between your eye and the real Moon.
What did you use as a ruler?	The model Moon.	The real Moon.

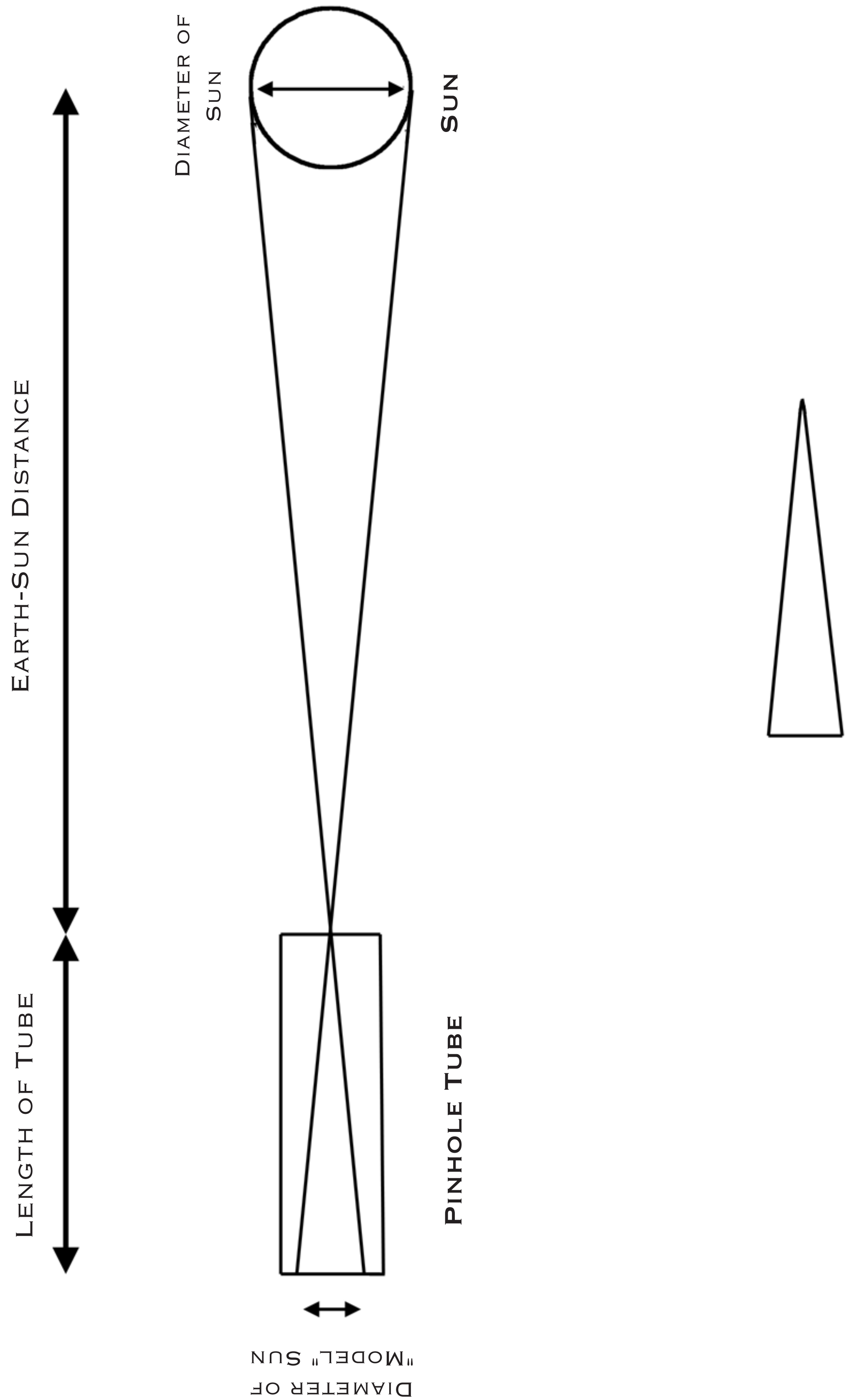
7. About 107.

How Far is Far?
Lesson at a Glance
Science Overview
Conducting the Lesson
Resources
Internet Resources & References
Moon Visibility Tables
Teacher Answer Key

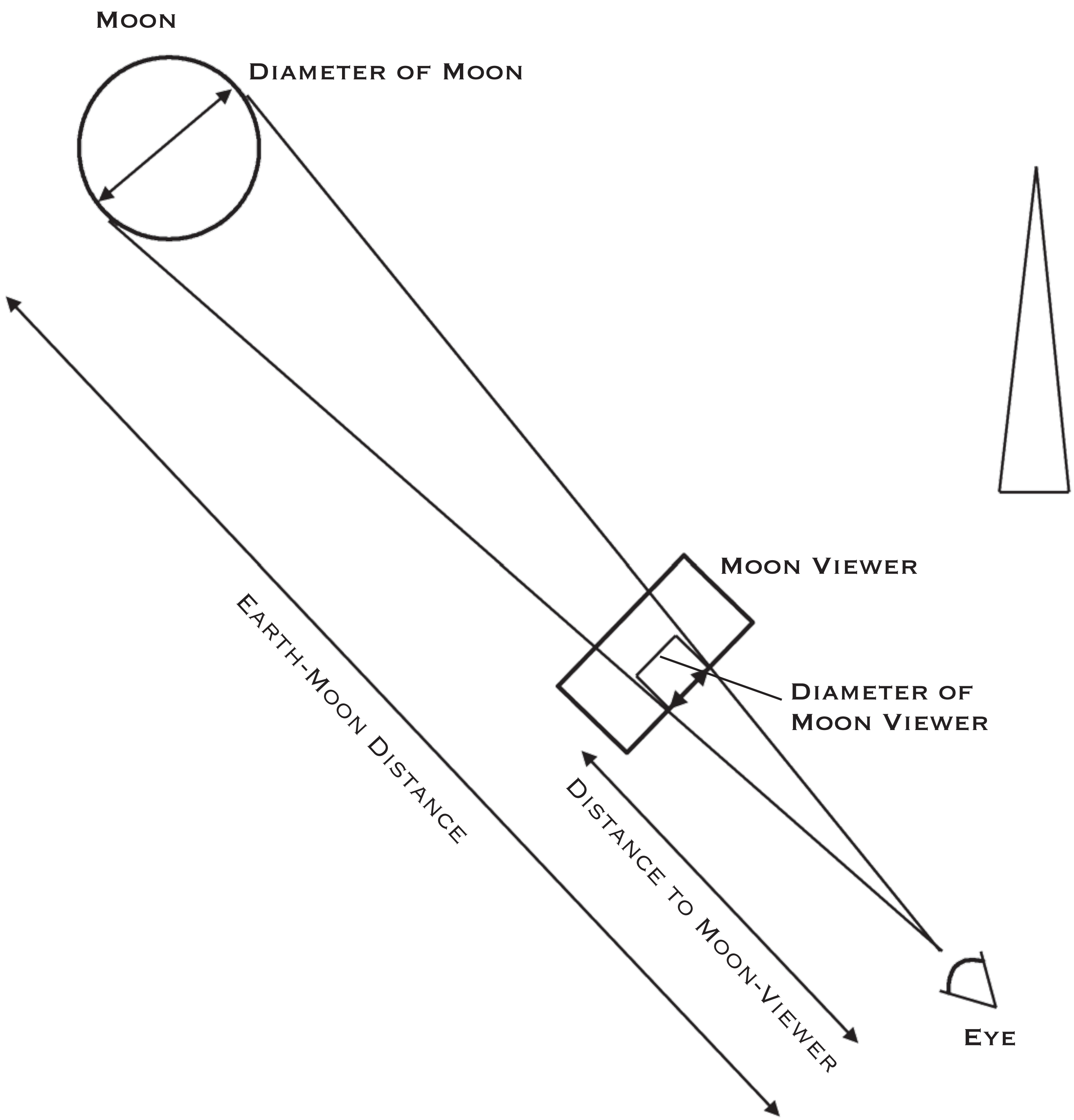
Tree Transparency



Sun Transparency



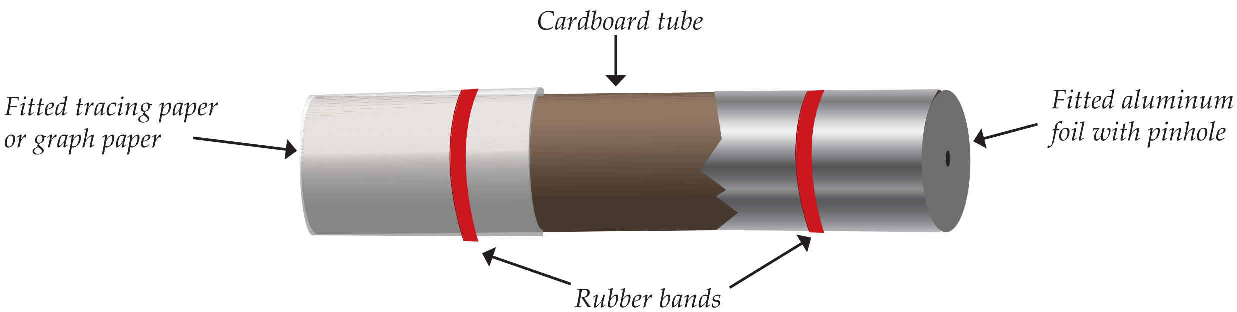
Moon Transparency



Name ______________________________ Date ____________

In this activity, you will measure the distance from the schoolyard to the Sun. You will use the pinhole tube, which you will make in Part I.

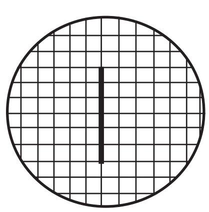
Part I: Building Your Pinhole Tube



Student Materials (Per pair):

- Cardboard paper towel tube
- Aluminum foil square (10 cm x 10 cm)
- Graph paper square (10 cm x 10 cm)
- 2 rubber bands
- Thumbtack or pin
- Metric ruler
- Sharp pencil
- Meter stick
- Masking tape
- Optional: Calculator
- Optional: Markers, stickers, other materials to decorate pinhole tube

1. Decorate your paper towel tube.
2. Place the aluminum foil square over one end of the tube and secure with a rubber band, as shown in the picture.
3. Place the graph paper over the other end and secure with a rubber band.
4. Use a thumbtack or push pin to carefully poke a small hole in the center of the aluminum foil.
5. Create a guideline on the graph paper by gently marking one of the lines near the center of the tube with your pencil. See figure below.



Construction Tip

The smaller your pinhole is, the better your pinhole tube will work. The foil rips easily, so be careful. If it does rip, get a new square of foil and try again. If the hole is not perfectly round, your pinhole tube will not work.

JOURNEY through the UNIVERSE

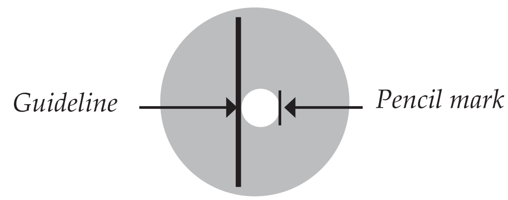
Part II: Using Your Pinhole Tube

1. Go outside with your partner. Take the pinhole tube, pencil, masking tape, and a meter stick with you. Decide who will be in charge of the meter stick, and who will be in charge of the pinhole tube.
2. One of you should hold the meter stick like a pole. The other should sit on the ground and aim the foil end of the tube at the Sun.

WARNING!
Do NOT look directly at the Sun or use the pinhole tube like a telescope!
Looking directly at the Sun will cause permanent eye damage!

3. Move the tube until you see a small image of the Sun on the graph paper. It looks like a circle of light, but it is really a model of the Sun!
4. Tape the tube to the meter stick to stabilize it.
5. Adjust the tube until one side of the Sun's image lines up with your guide line on the graph paper. Hold the tube steady and gently mark the other side of the Sun's image.

Have patience! It is not easy to hold the pinhole tube still and keep the Sun lined up with the guideline.



Part III: Measuring the Distance to the Sun

1. Use your ruler to measure the distance between your guideline and the pencil mark on the graph paper in millimeters.

   How big is the model Sun? ________________mm

2. Measure the length of your pinhole tube in millimeters.

   How long is your tube? ____________________mm

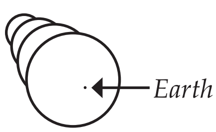
3. Use the model Sun as a ruler. How many model Suns span the length of the tube? (Hint: Divide the length of the tube by the width of the image.)

4. Look at the diagram below and find the triangles. The little triangle inside the pinhole tube is a model of the big triangle. These two triangles are similar triangles: their angles are identical and their sides are proportional.

5. Fill in the table. Since we have similar triangles and the little triangle is a model of the big triangle, can you fill in the table for the big triangle? (Hint: The first entry has been done for you. Remember, a model is proportional to the real object.)

Table	Little Triangle	Big Triangle
Where is the point of the triangle?		At the pinhole.
What forms the base of the triangle?		
What is the length of the triangle?		
How many bases fit along the length of the triangle?		
What did you figure out?		
What did you use as a ruler?		

6. Congratulations! You have now used the real Sun as a ruler. How many real Suns fit between the pinhole tube and the Sun?



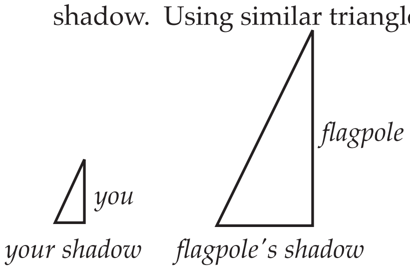
Questions

1. Is the image of the Sun a good model of the real Sun? Why or why not?

2. Imagine the Moon was blocking part of the Sun's light, creating a partial solar eclipse. What would the image on the graph paper look like?

3. If you did the experiment at different times of the year, the answers in the table would vary. Why?

4. Imagine you are 4' tall and are casting a 2' shadow on a sunny day. Next to you is a 12' flagpole that is also casting a shadow. Using similar triangles, figure out the length of the flagpole's shadow.



5. The Sun is 1,400,000 kilometers in diameter. How far away is the Sun from the Earth in kilometers?

6. Research the actual distance from the Earth to the Sun and check your answer from question number 5. Calculate your percent error.

   $$\text{Percent Error} = \frac{\text{Your Answer} - \text{Actual Answer} \ * 100}{\text{Actual Answer}}$$

Student Worksheet 2: A Model Moon

Name ____ Date ___________

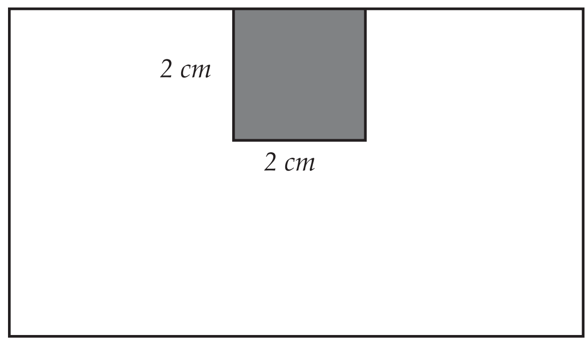
In this activity, you will create a Moon-viewer and determine the distance to the Moon.

Student Materials (per student):

- Student Worksheet 2
- Index card
- Transparent tape
- 3 meters of string
- Metric ruler
- Scissors

Part I: Creating the Moon-viewer

Cut a square in the top edge of an index card, with a length of 2 cm. Be careful in measuring and cutting the shape to ensure an accurate measurement.



Part II: Using your Moon-viewer

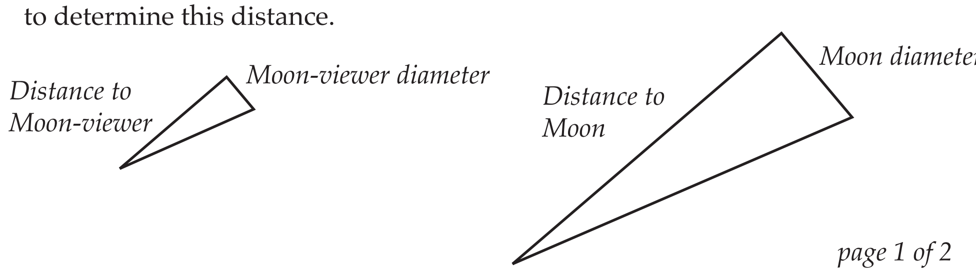
1. Use tape to attach the end of a 3-meter-long string to the bottom center of the Moon-viewer.
2. Tape the card to a window through which you can view the Moon.
3. Look at the Moon through the cutout of your Moon-viewer while holding the string up to your eye level.
4. Slowly adjust your distance from the Moon-viewer and let the string slide through your fingers to keep it taut. You have reached the correct distance when the Moon appears to just fill the cutout.
5. Mark the location of your eye on the string with an ink pen. Then, measure the distance, in centimeters, from the Moon-viewer to your eye along the taut string. Record the measurement in the Data Table on the next page.
6. Determine the distance to the Moon using similar triangles. Refer to the diagram below, and measurements you have already made, to fill in the data table to determine this distance.

Tip

If you do not have a Moon-facing window, you may choose to mount the index card on a stick or other temporary device and perform the activity outdoors.

Tip

If the Moon is not full, it will not fill the whole cut-out, just part of it. In this case, rotate the Moon-viewer so the tallest part of the Moon fits the length of the square.



JOURNEY through the UNIVERSE

Data Table		
Table	Little Triangle	Big Triangle
Where is the point of the triangle?		At my eye.
What forms the base of the triangle?		
What is the length of the triangle?		
How many bases fit along the length of the triangle?		
What did you figure out?		
What did you use as a ruler?		

7. You have now used the real Moon as a ruler. How many real Moons would fit between you and the Moon?