JOURNEY through the UNIVERSE

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.

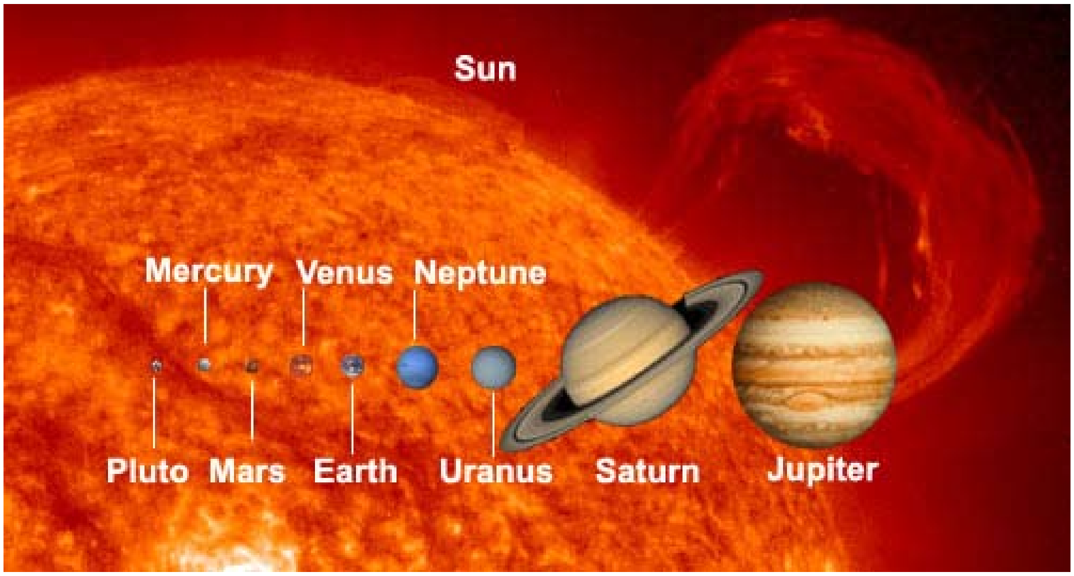

Figure 1: The relative sizes of the nine planets in comparison with the Sun. Note that the planets are listed in order of increasing size, not in order of distance from the Sun. (Picture credit: NASA/JPL; http://spaceplace.jpl.nasa.gov/sse_flipflop2.htm)

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.

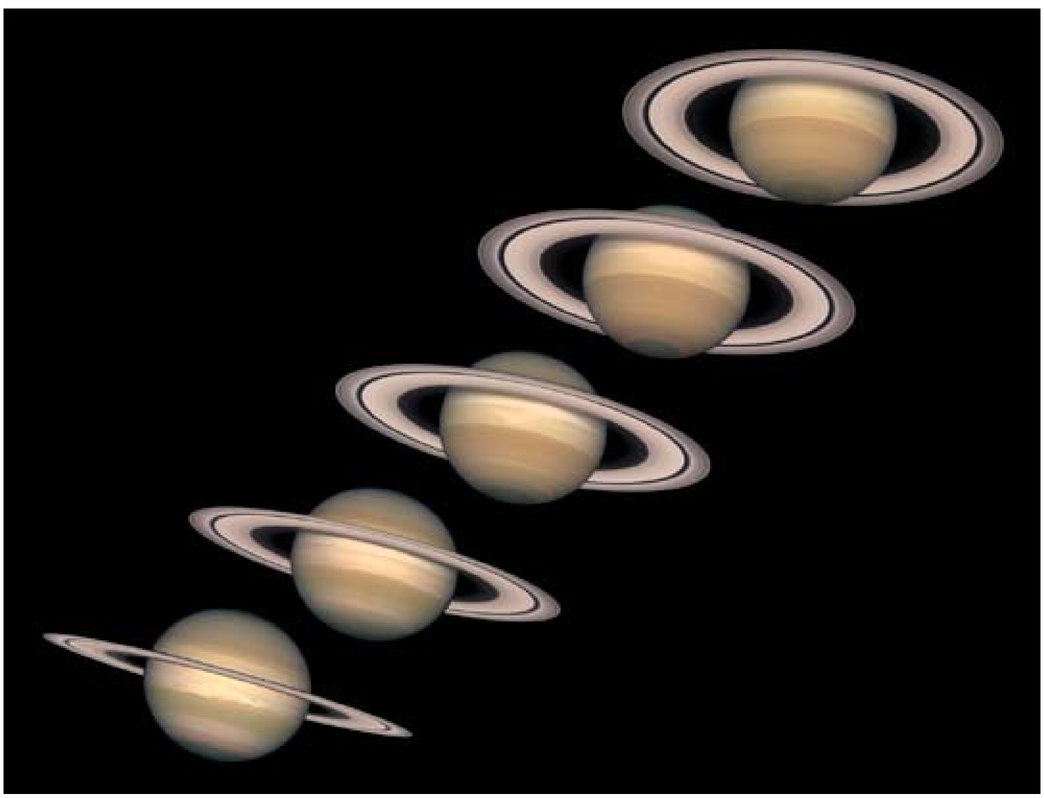

Figure 2: Saturn and its ring system seen from different angles by the Hubble Space Telescope in 1996-2000. Picture credit: NASA/JPL Planetary Photojournal; http://photojournal.jpl.nasa.gov/jpeg/PIA03156.jpg)

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^{o} 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.

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Resources

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.

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.

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

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.

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:

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:

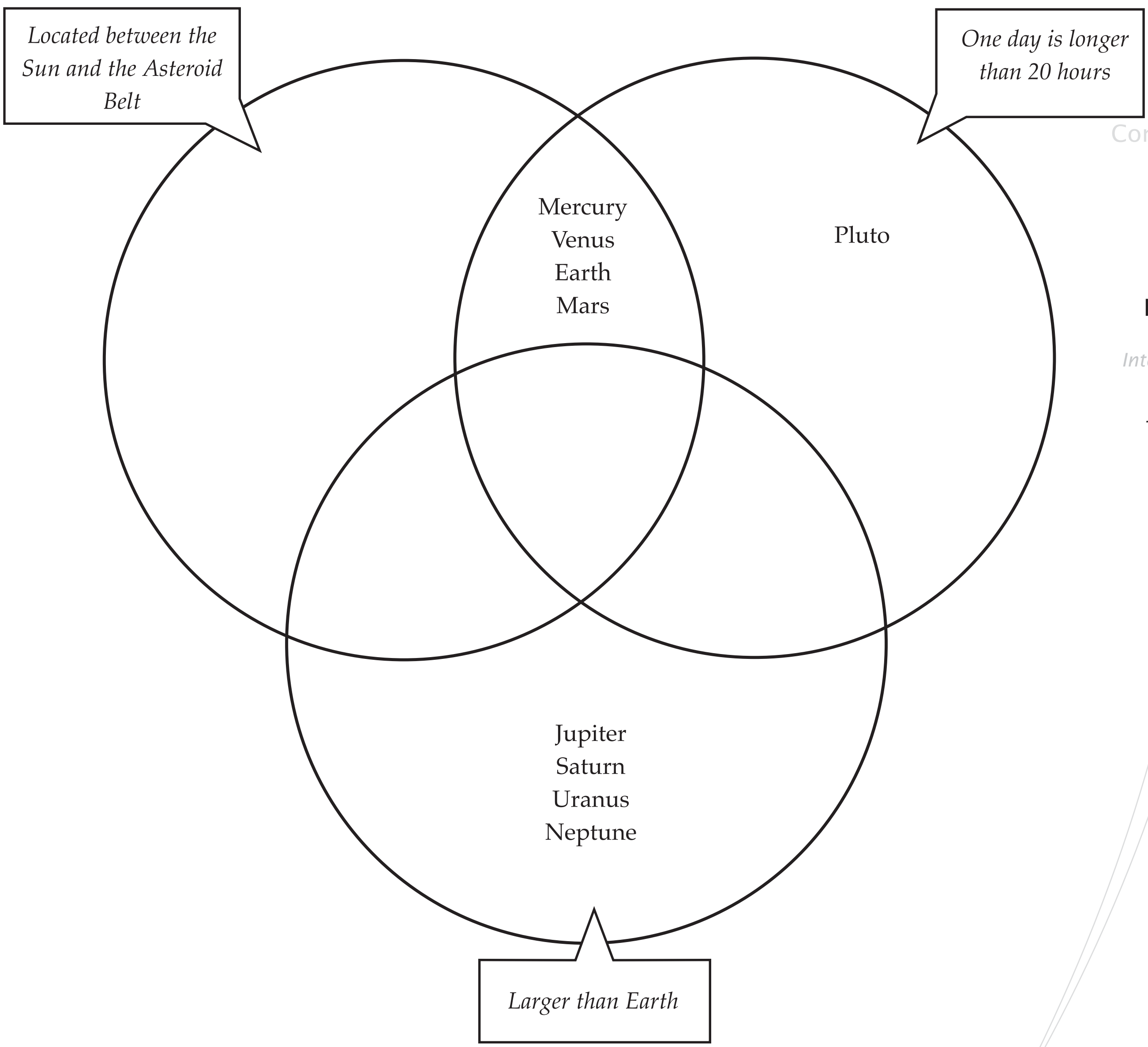
Astro for Kids
    www.astronomy.com/asy/default.aspx?c=a&id=1091/
Kids Astronomy
    www.kidsastronomy.com
NASA Kids
    kids.msfc.nasa.gov
Star Child
    http://starchild.gsfc.nasa.gov
Welcome to Astronomy for Kids!
    http://www.dustbunny.com/afk/

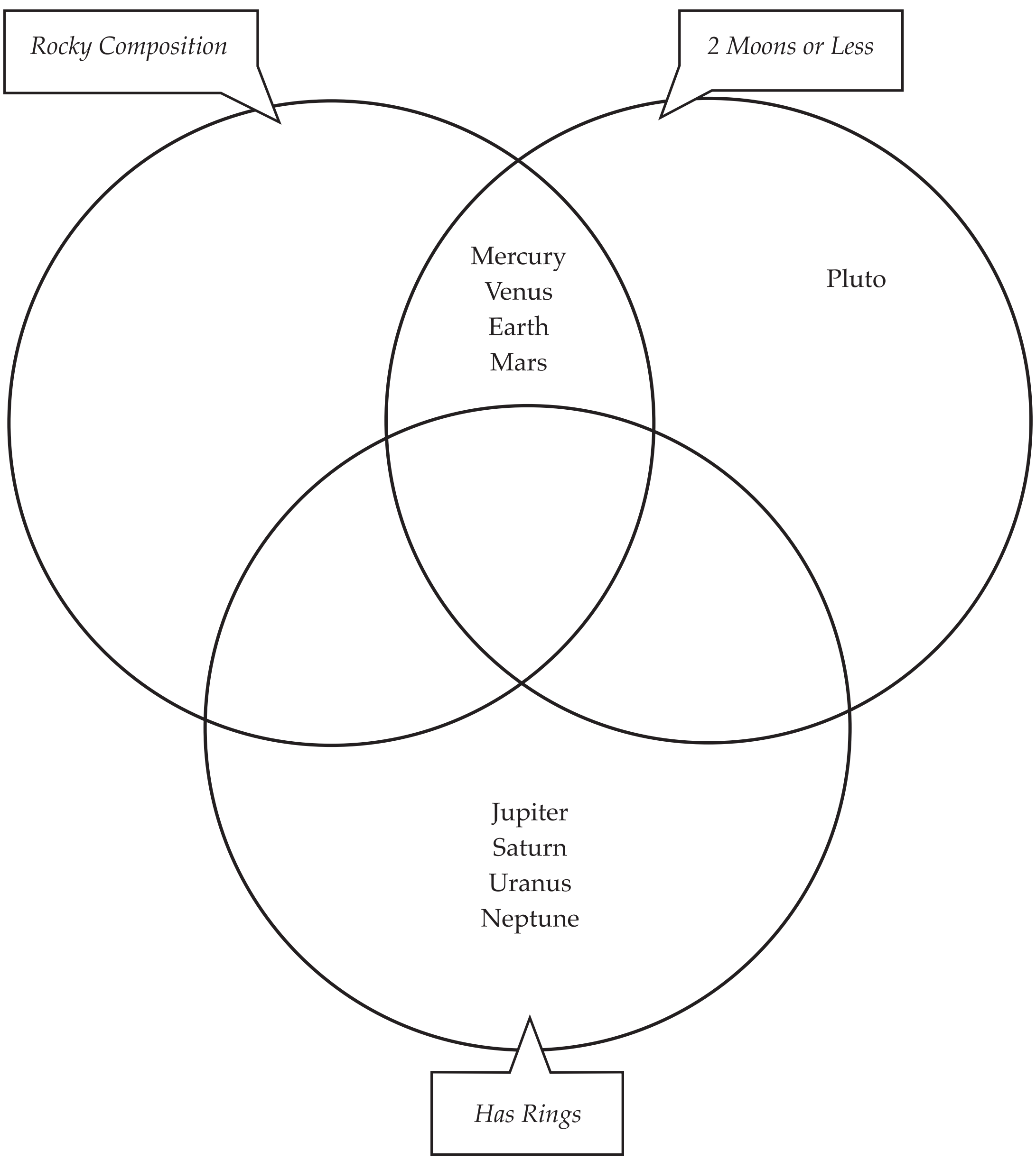
Teacher-Oriented Web Sites:

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.

____

____

____

____

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.

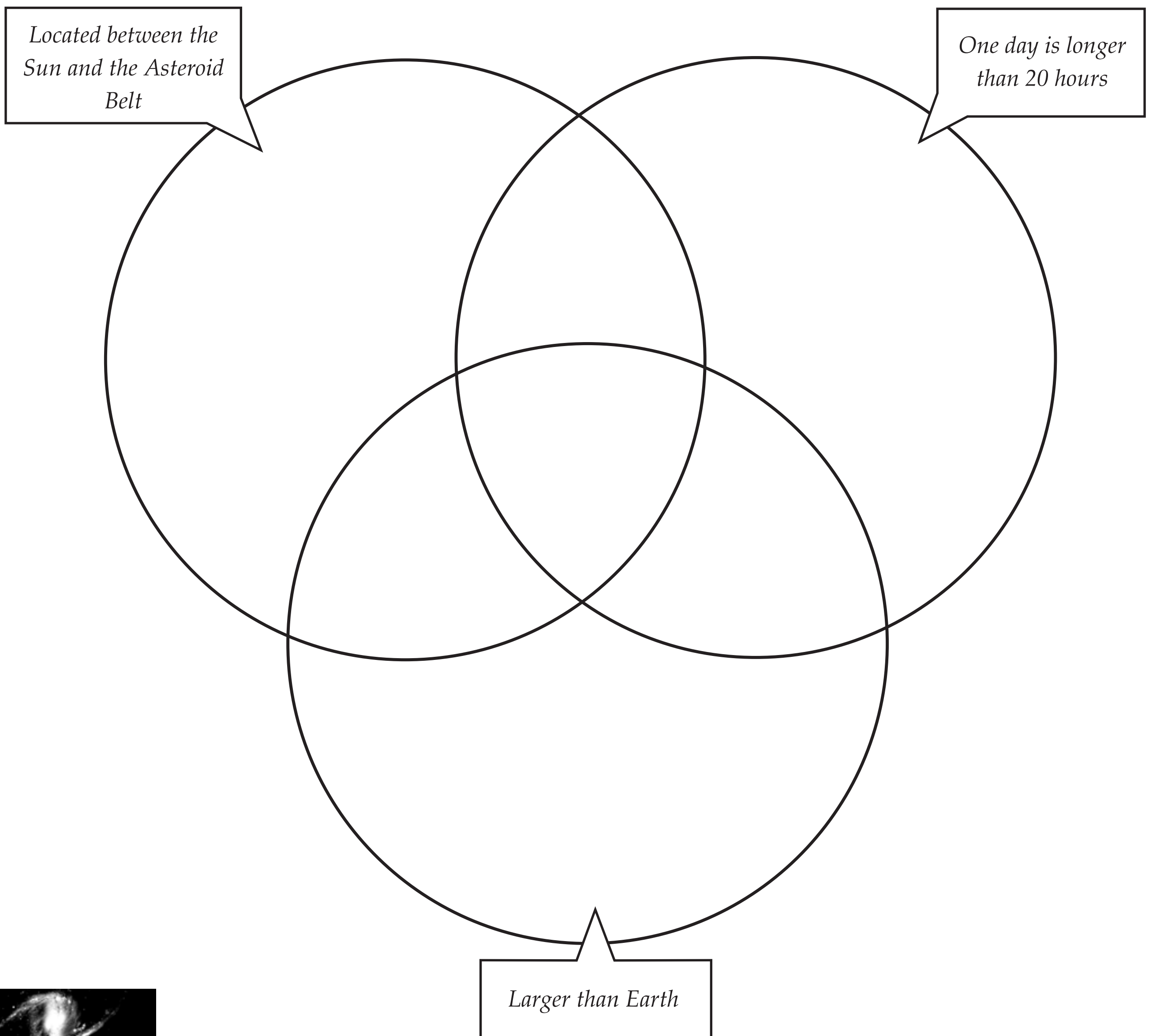
3. Prepare a short 3-5 minute presentation to the class describing your planet. Use your brochure as a visual aid.

Student Worksheet 3

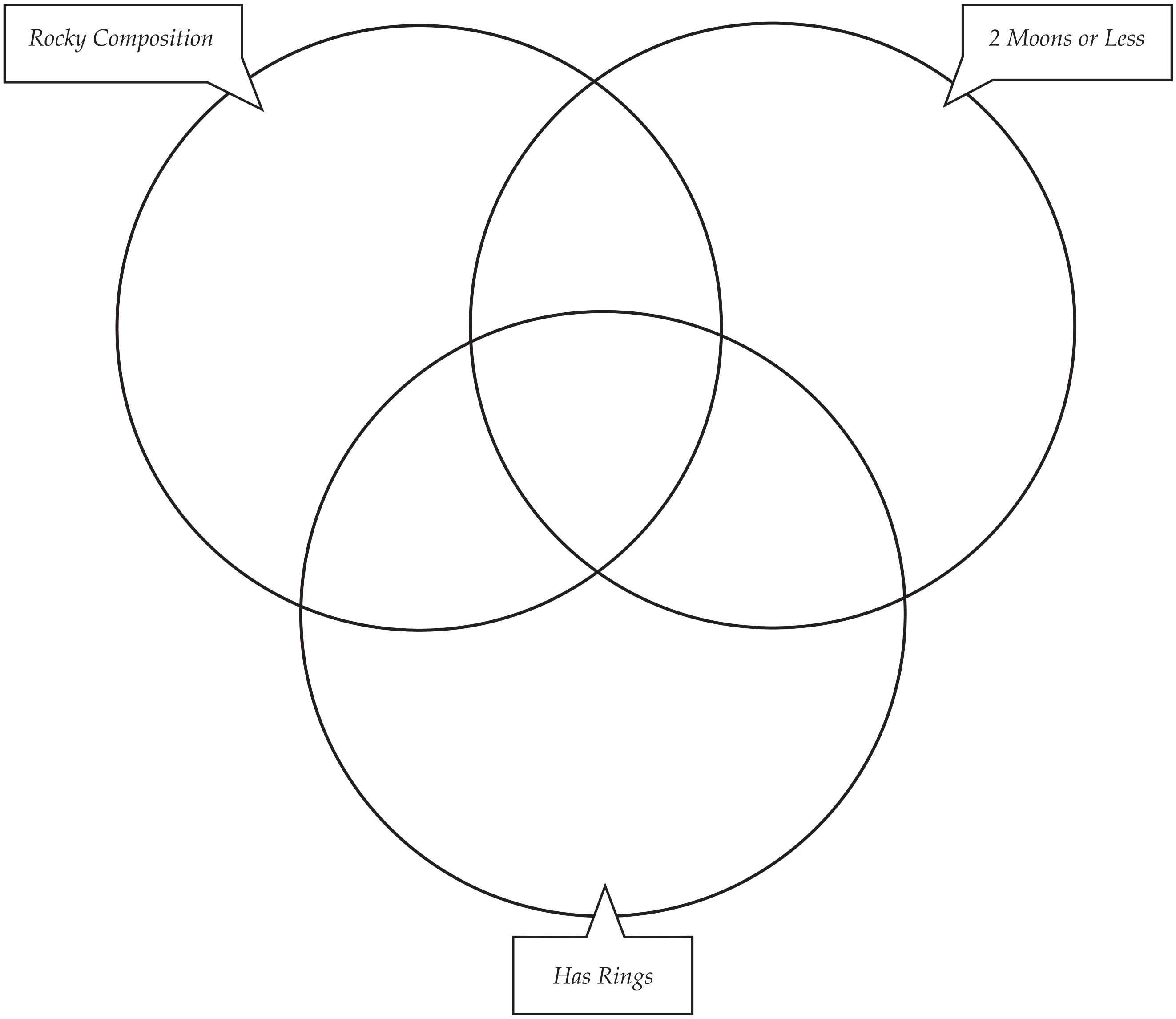
Name ______________________________ Date __________

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.



JOURNEY through the UNIVERSE



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.