Voyage: A Journey through our Solar System

Grades 5-8

Lesson 6: Where to Look For Life?

On a visit to the National Mall in Washington, DC, one can see monuments of a nation—Memorials to Lincoln, Jefferson, and WWII, the Vietnam Veterans Memorial Wall, and Washington Monument. Standing among them is *Voyage*—a one to 10-billion scale model of our Solar System—spanning 2,000 feet from the National Air and Space Museum to the Smithsonian Castle. *Voyage* provides visitors a powerful understanding of what we know about Earth's place in space and celebrates our ability to know it. It reveals the true nature of humanity's existence—six billion souls occupying a tiny, fragile, beautiful world in a vast space.

Voyage is an exhibition that speaks to all humanity. The National Center for Earth and Space Science Education is therefore making replicas of *Voyage* available for permanent installation in communities worldwide (http://voyagesolarsystem.org.)

This lesson is one of many grade K-12 lessons developed to bring the *Voyage* experience to classrooms across the nation through the Center's *Journey through the Universe* program. *Journey through the Universe* takes entire communities to the space frontier (http://journeythroughtheuniverse.org.)

The *Voyage* exhibition on the National Mall was developed by Challenger Center for Space Science Education, the Smithsonian Institution, and NASA.

Copyright July 2009

Lesson 6: Where to Look for Life

Lesson at a Glance

Lesson Overview

It is the most exciting question one can ask of the Solar System: is life unique to Earth, or are there abodes of life on other planets—even moons? A starting point is concluding that life as we know it requires liquid water. Given this constraint, in the first Activity students explore a mathematical model for how temperature varies with distance from the Sun. It allows them to find the 'happy place' for possible life—the range in distance from the Sun within which a planet might contain liquid water. At first glance, it appears only Earth exists within this range. Students then plot the actual observed temperatures for planets and moons, which demonstrates that more than just distance from the Sun accounts for planetary temperature, leading to potentially many abodes of life in the Solar System. In the second Activity students research the broader requirements for an abode of life, and whether these requirements are found on other worlds.

Lesson Duration

Three or four 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.

Standard B3: Transfer of energy

The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

AAAS Benchmarks for Science Literacy
Benchmark 4B8
Fresh water, limited in supply, is essential for some organisms and industrial processes. Water in rivers, lakes, and underground can be depleted or polluted, making it unavailable or unsuitable for life.

Essential Questions

- What are the conditions necessary for life to exist?
- Where might we expect to find life elsewhere in the Solar System?

Concepts

Students will learn the following concepts:

- An object's distance from a heat source affects its temperature.
- A planet's temperature is affected by several factors, including the distance from the Sun, the presence of an atmosphere, and tidal heating.
- Certain conditions are required for life to exist, including the presence of liquid water.
- Worlds other than Earth may meet the criteria required for life to exist.

Objectives

Students will be able to do the following:

- Graph data and use the graphs to interpret how planetary temperatures result from the interaction of many factors.
- Identify the conditions needed to support life.
- Investigate other worlds in the Solar System that may be able to support life.

Science Overview

One of the most exciting goals in exploring the Solar System is the search for life. Several missions to planets throughout the Solar System have supported this search, from testing Martian soil for traces of organic materials to the attempt to confirm the existence of liquid water within Jupiter's moons Europa, Ganymede and Callisto. In recent years, an entirely new field of science has emerged around this goal: astrobiology. Astrobiology investigates whether life could or does exist elsewhere in the Universe.

Why is it important to prove—or disprove—that life is present elsewhere in the Universe? On a philosophical level, the search for life is an attempt to answer the question, "What is our place in the cosmos?" If we are alone, we are compelled to wonder why we are so special. On the other hand, if the Universe is teeming with life, what other varieties of life exist? If life is rare, we can come to a better understanding of the delicate harmony that exists on our planet and the importance of preserving it. If life exists elsewhere, then learning about alien biology may even help us better understand the nature of our own biology.

With these motivations in mind, the exploration of the possibility of life beyond Earth begins. The first logical place to look for signs of life is the neighborhood of the Earth—the Solar System—and the first question to ask is where in the Solar System to look first?

Temperature Range Suitable for Life ("Happy Places")

On Earth, life has been found in a variety of seemingly inhospitable habitats. Life can be found at extreme pressures below the ocean's surface, exposed to high levels of radiation within nuclear reactors, and extracting nutrients and energy from nearly every available source. Similarly, life's presence encompasses a broad range of temperatures. Life has been found from frigid Antarctica to the scalding thermal pools (115°C or 239°F) in Yellowstone National Park. However, while the range may be wide, it is not infinite. In frozen water, the chemicals and molecules that are essential to the processes of life cannot be dissolved or moved. Penguins and polar bears that survive in seriously sub-freezing temperatures use stored fat and insulation to maintain a high internal temperature and depend upon an unfrozen environment nearby to provide food. For example, penguins can tolerate the Antarctic winter (-60°C or -76°F) only because they can gorge beforehand on fatty fish in the relatively warm and unfrozen ocean. Antarctic icefish, on the other hand, really live and function at a body temperature below freezing (-3°C or 27°F) by virtue of a biochemical antifreeze, and the fact that salty ocean water has a freezing temperature a bit below 0°C. Some life thrives at 115°C (239°F), but not at higher temperatures, possibly because enzymes and proteins necessary for life cannot exist at higher temperatures.

With these considerations in mind, a temperature range to use as a rule of thumb in judging the likelihood of life's presence on a foreign world can be determined: it is simply the temperature range where liquid water exists on the surface of Earth under normal atmospheric pressure (remember that the freezing and boiling points of water depend on the pressure). This range is 0ºC to 100ºC (32ºF to 212ºF). There are life forms on Earth that can tolerate slightly colder or hotter environments, but the properties of liquid water can be used as a good guide and the results amended by remembering that we can deviate from the temperature range defined above—but just a little!

The Effect of Sunlight on Planetary Temperatures

Intuitively, one of the most significant influences on a planet's temperature in the Solar System is its distance from the Sun. A planet absorbs energy from the light radiating from the Sun, and this raises the planet's temperature. The planet re-radiates that energy into space as infrared light, which lowers the planet's temperature. Since both of these processes are occurring simultaneously, the planet's temperature reflects equilibrium between the energy absorbed from sunlight and the energy re-radiated into space.

Based on this consideration, one would expect that the closer the planet is to the Sun, the higher its temperature. If planets were just pieces of rock floating around in space, this would be the case. One way to estimate temperatures at different distances from the Sun, therefore, is to use the idea of a "rock" that absorbs all sunlight striking it and also re-radiates the energy in the best possible way. Scientists call this kind of "perfect absorber" and "perfect emitter" a blackbody (because if an object absorbs all light striking it, it does not reflect anything toward a viewer—which is how we see most of the objects that we see—and, therefore, looks black). However, several factors can reduce or enhance a planet's ability to retain the energy of sunlight, causing the actual temperature to differ from these simple expectations; planets are not simple rocks floating around in space; that is, planets are not blackbodies!

Atmosphere as Temperature Moderator

The presence of an atmosphere moderates a planet's daily temperature variations. If sunlight falls on an object in space, it heats up quickly, but if the object is then shaded from sunlight, it cools off just as quickly. This means that if a planet has no atmosphere, a given point on the planet's surface can see extreme variation in temperatures between day (when the Sun heats up the surface) and night (when the surface can cool off rapidly). For example, Mercury's atmosphere is very tenuous (virtually a vacuum) and, as a result, the daytime temperatures can be as high as 260ºC (500ºF), while at night the temperatures can drop down to -120ºC (-180ºF). In the other extreme, Venus's greenhouse atmosphere keeps the temperatures on the surface at the constant 460ºC (860ºF), with little effect from whether it is day or night. In between, Earth's and Mars's atmospheres moderate the daily changes in temperature by not allowing the infrared light to escape as easily during the night (when there is no sunlight to warm up the surface). For example, on Earth the temperatures typically vary during the day by only about 10-20°C (20-40°F). The largest daily temperature differences on Earth occur in deserts, where the temperature difference between the day and the night can reach about 40ºC (75ºF), changing from 66ºC to 24ºC (150ºF to 75ºF). The presence of an atmosphere also moderates temperatures between equatorial regions (which receive a lot of sunlight year-round) and the poles (which do not.)

Because the gas giants (Jupiter, Saturn, Uranus, Neptune) are mostly made of gas, their surface temperatures cannot be measured. Instead, scientists use the temperature on the cloud tops—which are the features seen on the planets when observed with telescopes—as an estimate for the temperature environment near these planets. The temperatures on the moons around the giant planets (such as Jupiter's well-known moons Europa, Io, Ganymede, and Callisto) have solid surfaces but very little in the way of an atmosphere; so their temperature varies somewhat—but it is always very cold. Saturn's moon Titan is an exception, since it not only has a solid surface, but also has a substantial atmosphere, which regulates the (cold) temperatures on this remote moon, limiting the temperature variations.

Table 1. Atmospheric pressures and surface temperature ranges on worlds in the Solar System whose surface can be observed.

World	Temperature Range (°C)	Atmosphere
Mercury	-123 to +259	minimal
Venus	+457	very thick
Earth	-89 to +55	thick
Earth's Moon	-113 to +127	minimal
Mars	-134 to +27	thin
Europa (moon of Jupiter)	-203 to -149	very thin
Io (moon of Jupiter)	-153	(trace)
Ganymede (moon of Jupiter)	-203 to -149	(trace)
Callisto (moon of Jupiter)	-203 to -149	(trace)
Titan (moon of Saturn)	-179 (surface)	thick
Pluto (dwarf planet)	-233 to -213	very thin

Greenhouse Effect

One factor of the atmosphere that affects planetary temperatures is the greenhouse effect. Carbon dioxide and other greenhouse gases in the atmosphere let in visible light from the Sun but do not let out all of the cooling infrared light. On Earth, the greenhouse effect raises the average planetary temperature about 30-40°C (54–72°F) higher than it would be otherwise. While this makes the Earth comfortable to those living here, the greenhouse effect can also lead to harsh extremes. On Venus, which has a thick atmosphere of carbon dioxide and high-altitude clouds of noxious chemicals, the greenhouse effect is so pronounced that the planet has a nearly constant temperature of around 460°C (about 860°F).

Planetary Albedo

The reflectivity of a planet—termed its "albedo"—also can influence its temperature. A perfectly black object (a blackbody) absorbs all light falling on it. On the other hand, reflective objects absorb only some of the light energy that falls upon them. If a black object and a reflective object were located at the same distance from the Sun, the black object would have a higher temperature. This isn't too mysterious. On a sunny day, the hood of a black car will have a higher temperature than the hood of a white car. Jupiter's moon Europa, which is covered in a white layer of ice, reflects much of the light that falls on it and is, therefore, cooler than a dark object would be at the same location. There is no such thing as a perfectly black object; everything reflects at least a little light. However, some objects, like asteroids, are a fairly good approximation to a blackbody because of their low reflectivity.

Internal Energy Source

Sunlight is an important energy source for all planets; for many planets, it is the only substantial energy source. However, there are planets that have internal energy that gives rise to processes that shape their surface and can also influence their temperatures. For example, Earth has some geothermal energy that keeps some of the inner parts of the planet molten. This energy gives rise to many of the processes that shape the face of the planet—earthquakes, volcanoes, even the magnetic field that shields the Earth from much of the Sun's harmful radiation—but it is still just a small contribution to Earth's total energy when compared to the amount of energy that sunlight provides to Earth. Geothermal energy does not significantly affect Earth's surface temperature in general—just locally when events such as volcanoes occur. Other planets have internal energy sources, as well. For example, Jupiter is undergoing gravitational compression—it is basically being compressed by its own weight—and this process releases energy. In fact, Jupiter radiates more energy than it receives from the Sun. Saturn also radiates more energy into space than it receives from the Sun. Gravitational compression explains part of Saturn's excess energy, but some of it may come from "helium rain" deep in its interior—helium droplets condensing in the high pressure. Neptune belongs in this group of "excess radiators," as well. The source of its internal energy is probably similar to those of Jupiter and Saturn.

Tides

Another temperature-altering influence is tides. On Earth, the tides of the ocean are caused by the Moon tugging on one side of the Earth more strongly than the other, in this way slightly distorting the shape of the Earth. The fluid part of the Earth (the oceans) distorts more easily than the solid parts (the continents) causing a tidal bulge to slosh around the Earth as the Earth rotates. While the tides do not raise the global temperature on Earth, similar processes can have a significant effect on other worlds in the Solar System. The moons of Jupiter experience tidal forces due to Jupiter and also due to the other moons. The forces on the largest moons—Io, Europa, Ganymede, and Callisto—are strong enough that the tides bend and flex the rock of the crust and core, creating heat. On Io, the heat is great enough to produce volcanoes and evaporate any water it may have once had. On Europa, the heat may be enough to melt a global ocean beneath a crust of water ice. The moons Ganymede and Callisto are similarly affected, but to a less extent due to their large size and greater distance from Jupiter. However, it is possible that this effect is still sufficient to give rise to salt water oceans under the moons' surfaces; there is some evidence for this possibility, but it needs to be confirmed with more conclusive data.

Earth as an Abode of Life

Temperature is not the only factor in determining whether a world is suitable for life—though it may be the most important. Earth is located at just the right distance from the Sun to make temperatures on the planet hospitable for life. But there are other factors that make Earth an ideal place for life to thrive. Earth's atmosphere provides protection from the Sun's harmful radiation. Temperatures across most of the Earth allow liquid water to exist, and Earth receives plenty of sunlight to provide energy for life processes. But how does Earth's favorable environment for life compare to the other worlds of the Solar System?

Liquid Water on Other Worlds in the Solar System

There are not many other places in the Solar System where liquid water might exist. Most other places in the Solar System seem either too hot (e.g., Mercury, Venus) or likely too cold (e.g., the outer planets and their moons) for liquid water. On Mars, the surface temperature and air pressure are both too low for liquid water to exist—although conditions on Mars long ago allowed for abundant water. It is possible that liquid water still exists below Mars's surface. Astronauts visiting the Moon found it devoid of water in the areas they explored. Yet there is some evidence that there might be frozen water near the north and south poles of the Moon. As described above, there is evidence for liquid water on Jupiter's moons Europa, Ganymede, and Callisto, where oceans may exist underneath the surface. At present, the evidence is fairly strong for Europa, but only preliminary for Ganymede and Callisto.

Energy Source

Life requires a source of energy. The Sun supplies most of the energy that life uses on Earth and is responsible for the global climate. Plant life survives by extracting the energy in sunlight through photosynthesis. Higher life forms—from hummingbirds to humans—derive their energy by consuming plants or by consuming animals that consumed plants. The web of life on Earth is constructed mostly around the energy in sunlight. However, there are places on Earth (such as deep underground or in ocean bottoms) where sunlight cannot reach. There are creatures there that extract energy from their surroundings, without need for sunlight. The discovery of these kinds of creatures has caused scientists to consider whether places such as Jupiter's moons might be able to harbor life due to the tidal heating energy, even if sunlight may not be sufficient to support life processes so far away from the Sun.

Protection from Harmful Radiation

The atmosphere protects the Earth from many types of harmful radiation from the Sun, including high-energy light like ultraviolet (UV), X-rays, and gamma rays, as well as high-speed particles flowing out from the Sun as the solar wind. If a world has no atmosphere, life there would need another form of shielding from radiation. For example, when the astronauts went to the Moon, the visors on their helmets were specially designed to afford protection from the Sun's ultraviolet radiation since the Moon does not have an atmosphere. For life on other worlds, such protection might be provided by living underground or within structures that could be natural or created by the life in question. An organism may also have some physical or biochemical adaptation that helps it remain resistant to radiation. For example, there are life forms that have been found thriving inside nuclear reactors.

Stable Environment

Having an environment where the temperature does not vary too much may be essential if complex forms of life are to flourish and evolve over long periods of time. As discussed earlier, on Earth the atmosphere and oceans moderate day-to-night temperature changes to only about 10-20°C (20-40°F). On the Moon, which has no atmosphere, the temperature changes by 300°C (over 500°F) from day to night. That much of a temperature change would not be conducive to life as we know it. Subterranean environments on other planets or moons might have stable enough environments, even if the surfaces are not sufficiently hospitable. The environment also needs to be geologically stable; for example, contant landslides would not be conducive for life to exist.

Modeling Planetary Temperatures

In the discussion of temperatures on different planets, it is difficult to keep track of the exact temperatures in different parts of the Solar System—it is easy to get lost within the multitude of numbers! One way to solve this problem is to use mathematical models to represent temperatures. Models, in general, are representations of an object or phenomenon at a different scale or in a different medium. For example, a model airplane is an example of a physical model—it is a model of a real airplane that can be held. Mathematical models are quantitative or symbolic representations of a concept, process, or phenomenon. For example, the multiplication tables reflect a shortcut to the process of counting. A bar chart may indicate the most popular ice cream flavors. The countdown process represents the liftoff procedures for a spacecraft. An example of a mathematical model would be a graph describing the temperature of a blackbody at different distances from the Sun (see Figure 1). The graph is a mathematical model of the real blackbody temperatures; the simplicity of Figure 1 makes it clear why using mathematical models to represent this kind of data is a very useful tool in exploring the Earth's neighborhood, the Solar System.

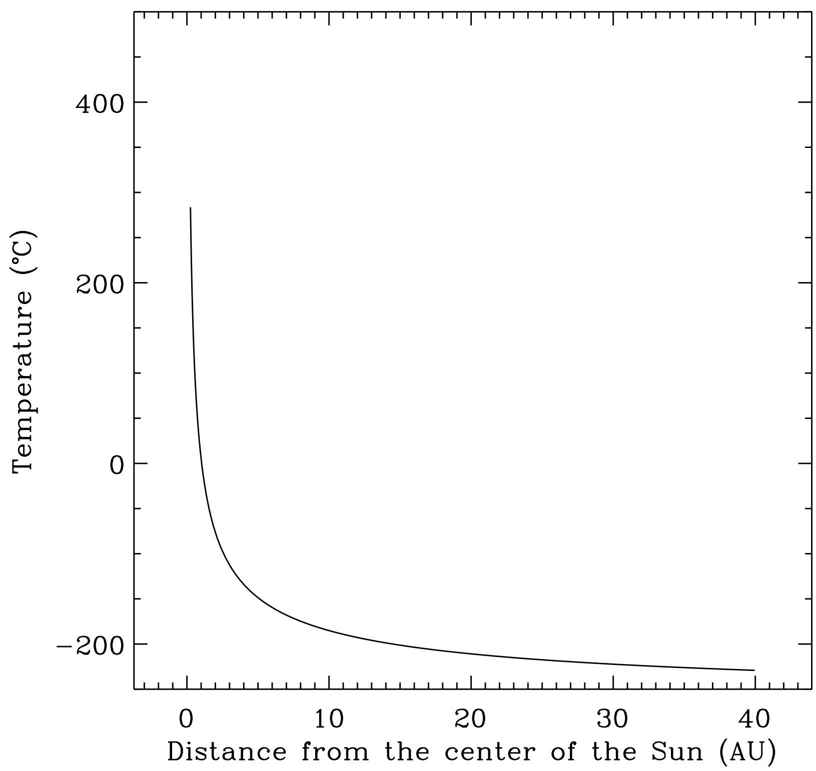


Figure 1. An example of a mathematical model: temperatures of a blackbody at different distances from the Sun can be represented by a graph. The temperatures are given in degrees Celcius and the distances in AU (Astronomical Unti), which is the average distance from the Earth to the Sun. One AU is about 150 million km, or 93 million miles.

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Chalk board or white board

Preparation & Procedures

Have students brainstorm possible reasons why Earth is so hospitable for life, and record their answers on the chalk board or white board. You can ask the following questions:

- What is it about where we are that makes Earth a "Happy Place," where so much life can thrive? (*Desired answer: we are at just the right distance from the Sun*) What is it about our distance from the Sun that makes Earth so special? (*Desired answer: we are not too hot or too cold*)

- What is it about the temperature that allows life to exist? Students may need a hint; everything that is alive has chemical reactions occurring—this is called biochemistry. What is abundant on Earth that allows these chemicals to come together and interact? (*Desired answer: water*) Will just any kind of water do? (*Desired answer: liquid water*) Why do chemical reactions not occur easily in ice? (*Desired answer: ice is a solid and the molecules are locked into place and cannot move freely*) Why don't chemical reactions occur easily in water vapor? (*Desired answer: the molecules are moving too fast to interact*)

- If we were going to look for a world where life might exist elsewhere in the Solar System, what would we look for? (*Desired answer: a world where liquid water could exist*) What would we need to know about each world to determine if liquid water could exist? (*Desired answer: the world's temperature*)

NOTES:

Where to Look for Life

Lesson at a Glance

Science Overview

Conducting the Lesson

Warm Up & Pre-Assessment

Activity 1: Happy Places

Activity 2: Earth vs. Other Worlds

Lesson Wrap-Up

Resources

Activity 1: Happy Places

Students will first predict, then graph, the expected temperature of an object at increasing distances from the Sun. Students then identify the range in distance from the Sun within which liquid water can exist, and determine which planets are found in this range. On their graphs students then plot the actual observed temperatures of planets and moons, and determine that temperature on these worlds does not behave as predicted—which allows for the possibility of many abodes of life in the Solar System.

Teacher Materials (Per Class)

- Transparency of Graph A
- Overhead projector
- (Optional) Transparency of Data Table 1
- (Optional) Transparency of Data Table 2

Student Materials (Per Student)

- Student Worksheet 1
- Student Worksheet 2
- Data Table 1
- Data Table 2
- Graph paper
- Colored pencils
- Ruler
- Research material (Internet, library) on the Solar System

Preparation & Procedures

1. Make a class set of Data Table 1 and Data Table 2 (or one transparency copy to use for the whole class, if you choose this approach). Make a transparency of Graph A.

2. In order for students to determine which worlds may harbor life, they need to determine at what distances from the Sun liquid water can exist. In order for the students to design their own experiment, you can ask the following questions:

    a. How can we determine the temperature at various distances from the Sun? (*Desired answer: we could carry an object to different distances from the Sun*)
    b. What would happen as we move this object farther away from the Sun? (*Desired answer: the temperature would drop*) Closer to the Sun? (*Desired answer: the temperature would rise*)

c. If we have the object at a given distance from the Sun, would the object keep heating up forever as long as it is exposed to sunlight? (*Desired answer: it will eventually stop heating*)

d. Why will the temperature level off or reach equilibrium? (*Desired answer: the heat it absorbs is equal to the heat it radiates*)

e. Will the color of the object affect the equilibrium temperature? (*Desired answer: the darker the object, the hotter it will be*) What color would absorb the most heat? (*Desired answer: black*) What color would absorb the least heat? (*Desired answer: white*)

TEACHING TIP

This activity can be done individually or in cooperative groups.

3. Tell students that scientists have actually calculated the temperature of a very black object, called a blackbody object, at different distances from the Sun.

   a. How could we determine at what distance from the Sun the temperature is just right for liquid water? (*Desired answer: find the temperature of a blackbody object at different distances from the Sun, and see where the range for temperatures allowing liquir water is—we'll call this range the "Happy Place"*)
   b. What is the temperature at which liquid water can exist? (*Desired answer: 0-100°C, or 32-212°F*)
   c. How could we determine which worlds in the Solar System may be suitable for life? (*Desired answer: find the blackbody temperatures at each worlds' distance from the Sun and see which ones fall in the "Happy Place"*)

4. Hand out copies of Student Worksheet 1. Students will label the x- and y-axis on two graphs: x is "Distance from the Center of the Sun," and y is "Temperature." The temperature range for both graphs is –250°C to 500°C. Graph 1 will cover the Solar System to Pluto. Graph 2 will cover only the inner Solar System, to mid-way between Mars and Jupiter. (If the entire Solar System was plotted on one graph, the inner Solar System would be packed into a small region, because the distances between inner planets are much smaller than the distances between the outer planets.) Students will use the "Approximate distance from the center of the Sun" information in Data Table 2 to determine the range for the x-axes. Distances from the Sun are given in AU (Astronomical Unit; the average distance from the Sun to the Earth). The ranges should be 0 to 40 AU for Graph 1, and 0 to about 3 AU for Graph 2.

5. Have students predict a curve for the blackbody temperatures on Graph 1. Graph A in the back of the lesson has three options for a blackbody curve. Display the Graph A transparency on the overhead projector and use it to discuss which prediction is correct (see the *Science Overview* for the correct curve.) Ask students to explain why the other curves may not be accurate. For example, the curve that goes through the origin indicates that the temperature close to the Sun would be 0°C.

6. Students can now plot the blackbody temperatures using Data Table 1 on both of their graphs. Discuss with the students how their prediction compares with what happens to an actual blackbody as it is moved farther from the Sun.

TEACHING TIP

You may want to remind the students of their goal. They are trying to find which worlds in the Solar System fall in the "Happy Place." Ask them what else is needed in order to determine this. (*Desired answer: the distances of the worlds from the Sun*)

7. Have students plot the "Happy Place," the zone on the graph in which liquid water can exist, by drawing a line parallel to the x-axis at the freezing and boiling points of water.

8. Using the distances (not the temperatures) from Data Table 2, have the students mark a point on the curved blackbody line at the distance of each of the worlds (planets and moons), labeled by the first letter of the name of each world. Do this on both graphs.

9. At this point students should stop to discuss which worlds appear to fall in the "Happy Place." The temperature of Earth should be near the freezing point of water. Have students list all of the worlds that seem to fall within the "Happy Place." You can point out to students that on Earth, there are life forms that thrive in slightly colder (down to -3°C, or 27°F) or slightly hotter (up to 115°C, or 239°F) temperatures, but not beyond these limits. Discuss with students whether this slightly wider "Life Zone" would increase the number of worlds in the Solar System that may harbor life.

10. Ask students if they think the worlds really behave exactly like blackbodies. How could we find out? (*Desired answer: let's plot the actual temperatures that scientists have determined, and see if the worlds do, in fact, behave like blackbodies*) Using Data Table 2, and with a different colored pencil, have students plot the actual temperature ranges in the inner Solar System (through Mars) on Graph 2. Do the same for the outer planets and some of their moons on Graph 1.

11. There are samples of Graph 1 and Graph 2 at the back of this lesson. (Note that the moons have been off-set slightly from the actual distance from the Sun so that they can all be easily read on the graphs.)

Reflection & Discussion

1. Have students brainstorm any questions that this activity might have generated. Make a list that the entire class can see. (For example: Why is the Moon's temperature range greater than Earth's, even though they are at the same distance from the Sun? Why do Venus, Jupiter, Saturn, Uranus, Neptune, Io, and Titan only have one temperature, while the other worlds have a temperature range? Why is Mercury's temperature range so large?) Have the class brainstorm answers to these questions in small groups.

2. Students will have discovered that the actual temperature ranges for the worlds are different from what we would have expected from the blackbody curve. What does this mean about the worlds that were plotted? (*Desired answer: they do not act like blackbodies. There must be something else going on.*)

3. Discuss with students the conditions that could cause the worlds' actual temperatures to deviate from the expected temperatures. (Such as the presence or absence of an atmosphere, greenhouse effect, tidal heating, etc.; see the *Science Overview* for more details.)

4. Have the class discuss those worlds which have temperature ranges inside the "Happy Place" but whose blackbody temperature is outside the "Happy Place." Ask the students if these worlds could have environments supporting life. (*Desired answer: yes, because they are in the right temperature range for liquid water to exist*) But is this the only requirement for life to be able to live there? Why would life be unable to thrive on Mercury, for example, if the temperature changes from –123ºC (-189ºF) to +259ºC (+498ºF) during its day, even if it goes through the "Life Zone"? (*Desired answer: the temperature environment is unstable*)

5. Could other worlds support life? Students plotted "surface temperature." Are there any places on a world which is outside of the "Happy Place" but which still could have liquid water somewhere on it? (*Desired answer: there could possibly be life that does not live on the surface of a world and lives underground instead, for example*) Students will explore the possibility of life in other locales besides the surface of a world, as well as the additional requirements for life on a world, in Activity 2.

Transfer of Knowledge

Have students research three worlds on Student Worksheet 2 to learn why the temperature is different from a blackbody object. Make sure that at least one student researches each world on the worksheet. Have students develop creative ways to report their finding to the rest of the class. As the findings are reported, have students fill in the rest of the worksheet.

Extensions

Have students research different climates on Earth. Students can compare this information to species population maps to see where different species live. Students can then research the characteristics of different species to see how they may have developed adaptations appropriate for their environments.

Teaching Tip

If this is too time-consuming for class, assign the *Transfer of Knowledge* as a homework assignment. Alternatively, a group of students could be assigned to one world, and the class can share their results.

Placing the Activity Within the Lesson

In Activity 1, students explored the observed temperatures on planets and moons in the Solar System, and compared the observations with blackbody predictions. Based on the temperature data, students came to the conclusion that other worlds in our Solar System could possibly have liquid water and therefore support life. But is a surface temperature inside the "Happy Place" the only consideration for life elsewhere? In Activity 2, students will attempt to understand other needs of living things and examine worlds that may provide them.

Notes on Activity 1:

Assessment Criteria for Activity 1

5 Points
- All qualities of an excellent graph are present.
- All questions from Student Worksheet 1 are clearly answered and correct.
- Student Worksheet 2 is complete and correct.

4 Points
- Missing one quality of an excellent graph.
- All questions from Student Worksheet 1 are clearly answered and mostly correct.
- Student Worksheet 2 is complete and mostly correct.

3 Points
- Missing two qualities of an excellent graph.
- All questions from Student Worksheet 1 are clearly answered and somewhat correct.
- Student Worksheet 2 is complete and somewhat correct.

2 Points
- Missing three qualities of an excellent graph.
- Most questions from Student Worksheet 1 are clearly answered and somewhat correct.
- Student Worksheet 2 is almost complete and somewhat correct.

1 Point
- Missing more than three qualities of an excellent graph.
- Some questions from Student Worksheet 1 are clearly answered and correct.
- Student Worksheet 2 has some entries which are correct.

0 Points
- No work completed.

Activity 2: Earth vs. Other Worlds

Students will identify the characteristics of Earth that are important for life as we know it, in addition to the presence of liquid water. They then research the planets and some of the moons of the Solar System to see if these worlds also possess the necessary characteristics, and might therefore be promising places to look for life.

Teacher Materials (Per Class)

- Flipchart paper

Student Materials (per student)

- Student Worksheet 3
- Research material (Internet, library) on the Solar System

Preparation & Procedures

1. Place the class into cooperative groups of three.

2. In addition to the right temperature for liquid water to exist, Earth has other characteristics that make it a "Happy Place." Have the class brainstorm a list of characteristics that they think are important for life, and record them on a sheet of chart paper. Lead students to the ideas of an energy source, stable environment, and protection from harmful radiation from the Sun. You can use leading questions like, "How do we get the energy to go to school? (*Desired answer: we eat food like meats and vegetables*) Where do vegetables get the energy to grow? (*Desired answer: the Sun*) What happens if you stay out in the sunlight too long? (*Desired answer: sunburn*) What causes sunburn? (*Desired answer: sunlight; specifically, ultraviolet light coming from the Sun*) Why do people worry about the depletion of the ozone layer? (*Desired answer: without it we have less protection from the harmful forms of sunlight*) In addition to protection, why else is our atmosphere beneficial? Hint: why does the temperature fluctuate by hundreds of degrees on Mercury and remains relatively constant on Venus? (*Desired answer: the atmosphere mediates temperatures in different parts of the planet and creates a stable environment*)

3. Let each group pick three planets or moons to investigate. (Be sure that all worlds are chosen.)

4. Students can use library and Internet resources to find descriptive characteristics of their worlds and fill in the chart in Student Worksheet 3. The students' research must include information on the four categories important for life (liquid water, an energy source,

stable environment, protection from harmful radiation). Students should keep in mind that just because a world's temperature did not fall in the "Happy Place" in Activity 1, it does not mean that liquid water could not exist somewhere else other than on the surface. However, there must be some evidence for the presence of liquid water on a world before we can suggest that it possesses this desired characteristic.

5. Have students prepare a presentation to the rest of the class on the worlds they researched. Their presentation must include a comparison between their worlds and Earth in the context of the four categories important for life. They must also discuss whether they found Earth's environment for life to be unique in the Solar System. Their presentation can also include descriptions of what a visitor to these worlds might experience.

Teaching Tip

You can make transparencies of Student Worksheet 3, and fill in the worksheet as students present on their worlds. Students can then use this information to fill in the remaining sections of their own worksheet. This way, they have the information for all of the worlds rather than just the three they researched.

Reflection & Discussion

1. Discuss the students' research by asking the following questions:
   - Which facts did you find interesting?
   - What are the differences between a planet and a moon? (Size is not a key factor since some moons are bigger than Mercury. Generally, a planet orbits the Sun, while a moon orbits a planet.) Why do students think Pluto is now considered a dwarf planet?
   - Of the planets and moons you researched, which one had the most number of features that were favorable for life? Which had the least? What kinds of adaptations or adjustments do you think a life form would need to make in order for it to live there?
   - What modifications would a colony of humans have to make to the environment of each of your worlds in order to survive? What resources would be available to them on the world and what would they have to bring along?
   - Did students learn anything new about the Earth during their research?

2. Based on student presentations, discuss the worlds that seem to be possibilities for supporting life. What characteristics do they have that make them desirable candidates? Do some worlds seem like greater possibilities than others? Why?

Where to Look for Life
Lesson at a Glance
Science Overview
Conducting the Lesson
Warm Up & Pre-Assessment
Activity 1: Happy Places
Activity 2: Earth vs. Other Worlds
Lesson Wrap-Up
Resources

Assessment Criteria for Activity 2

5 Points
- Unique characteristics were found for at least three worlds.
- At least three comparisons were made between the Earth and the other worlds.
- Student's work shows signs of research, and facts are accurate.
- Writing is clear and understandable.

4 Points
- Unique characteristics were found for at least three worlds.
- At least three comparisons were made between the Earth and the other worlds.
- Student's work shows signs of research, and facts are mostly accurate.
- Writing is clear and understandable.

3 Points
- Unique characteristics were found for at least three worlds.
- At least two comparisons were made between the Earth and the other worlds.
- Student's work shows signs of research, and facts are mostly accurate.
- Writing is clear and understandable.

2 Points
- Unique characteristics were found for at least two worlds.
- At least one comparison was made between the Earth and the other worlds.
- Student's work shows signs of minimal research.
- Writing content is difficult to understand.

1 Point
- Unique characteristics were found for at least two worlds.
- Comparisons were not made between the Earth and the other worlds.
- Student's work shows signs of little or no research.
- Writing content is difficult to understand.

0 Points
- No work completed.

Transfer of Knowledge

Scientists are finding planets around other Sun-like stars. Have students write a description of what they suppose scientists are looking for on those planets to see if there is a possibility of life there. Keep in mind that these planets are very far away, and scientists cannot detect details on the surface. Scientists can only hope to detect mass, distance from the star (and other properties of their orbits), and clues about their composition.

Answers could include the following: Scientists would look for these planets to be in the Happy Place, they would look for signs of water, signs of plants or elements in the atmosphere that might indicate the presence of life (such as oxygen, methane, carbon dioxide, or water vapor; elements like these are called biosignatures) in the planet's atmosphere. They would try and determine whether the planets are gas giants like Jupiter (and, therefore, most likely could harbor life only on moons around them) or rocky planets like the Earth.

Extensions

Have students research past and present spacecraft missions that have looked for life on other worlds.

Placing the Activity Within the Lesson

Students must understand that there are many characteristics that are needed in order for a world to be conducive for life, not only the right distance from the Sun. There are other worlds in our Solar System that could be abodes for life.

Notes on Activity 2:

Lesson Wrap-Up

Transfer of Knowledge for the Lesson

Have students write a mock proposal to NASA to explore one world in search of life. They should choose the world that they believe has the greatest probability of supporting life. They should use examples from class, their research, and the presentations of their classmates to support their proposal.

Assessment Criteria for the Lesson

5 Points

- Student could identify those worlds that may support life.
- Student participated in lesson.
- Student used ideas from class, research, and classmate presentations to support his or her proposal in the *Transfer of Knowledge for the Lesson*.
- Student used facts to support his or her proposal.
- Student's proposal was clear and understandable.

4 Points

- Four of the five criteria from above are met.

3 Points

- Three of the five criteria from above are met.

2 Points

- Two of the five criteria from above are met.

1 Point

- One of the five criteria from above is met.

0 Points

- No work completed.

Lesson Closure

Students should be able to identify worlds that they think might have environments that may currently support life, or may have supported life in the past. These can include Mars, Jupiter's moon Europa, and Saturn's moon Titan. If the preliminary evidence for the presence of sub-surface oceans on Jupiter's moons Ganymede and Callisto is confirmed, they might be able to support life in the same manner as Europa.

Extensions for the Lesson

- Have students research spacecraft missions to other planets (and their moons) and how the environmental conditions affected the construction of the spacecraft used for these missions. Does it matter whether the spacecraft lands on the planet or just observes it from orbit? (*Desired answer: yes, it does. For example, the spacecraft that landed on Venus were lost due to the extreme environment on the surface (high temperature, high pressure) within hours of their landing.*)

Curriculum Connection

Social Studies: Discuss the ethical implications of exploring other worlds. Possible topics: Do we have the right to move to places where life already exists or places where life could exist? Have we moved to places where indigenous life existed in the past here on Earth? Do we have the right to transform another world into a more Earth-like environment? Should we use natural resources from other worlds, or alter the natural beauty of other worlds?

- Discuss with your students the motivations for exploring other worlds. Some answers may include the following: curiosity; to find useful resources; to find a new place to colonize; if intelligent life forms exist, to see if we could learn about them; to find out whether we are alone in the Universe; or to better understand our place in the Universe.

Lesson Adaptation

Special Education: You can prepare Graphs 1 and 2 with blackbody curves drawn (but not the "Happy Places" line or the real planet temperatures—*Teacher Answer Key* has full graphs with all data marked), make copies for the class, and have students work directly on these rather than having them create their own graphs and plot every point of the blackbody curve from Data Table 1.

Resources

Internet Resources & References

Student-Friendly Web Sites:

NASA for Students
www.nasa.gov/audience/forstudents/5-8/

The Nine Planets
www.nineplanets.org/

Teacher-Oriented Web Sites:

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

NASA Astrobiology
astrobiology.nasa.gov/

NASA Astrobiology Magazine
www.astrobio.net/

NASA Astrobiology Magazine: Article on biosignatures
www.astrobio.net/news/article528.html

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

Smithsonian Institution – Exploring the Planets
www.nasm.si.edu/ceps/etp/

Voyage: A Journey through Our Solar System
www.voyagesolarsystem.org

Journey through the Universe
www.journeythroughtheuniverse.org

Teacher Answer Key

Please note that Graph A, Graph 1, and Graph 2 are provided on subsequent pages.

Student Worksheet 1

4. Suggested x-axes: Graph 1: 0-40 AU
   Graph 2: 0-3 AU

5. See Graph A for possible predictions, and Graph 1 for the correct line.

7. See Graphs 1 and 2 for blackbody lines. Answer to the question varies according to students' predictions.

8. 100ºC (212ºF)

9. 0ºC (32ºF)

12. Answers may vary depending on students' expectations.

13. Answers vary according to students' expectations. Planets and moons do not behave as blackbodies. We can find out whether they do by determining what their real temperatures are. See Graphs 1 and 2 for the temperature ranges in different worlds.

Student Worksheet 2

World	Description of temperature and relation to blackbody temperature *(Determined by looking at Graph 1 and/or Graph 2)*	Reason(s) for characteristics of the temperature *(Determined by research)* Choose one or more from Table 1	Reason(s) for characteristics of the temperature *(Determined by research)* Describe in your own words
Mercury	Large temperature range, overlaps blackbody temperature	1, 5, 8	Mercury has minimal atmosphere to regulate temperatures; changes in the temperatures between day and night are extreme.
Venus	Single temperature, extremely high, much higher than blackbody temperature	1, 3, 6, 8	Venus is extremely hot because its carbon-dioxide-rich atmosphere allows for a very pronounced greenhouse effect. The thick atmosphere lets in sunlight but does not allow heat to escape. As a result, day and night temperatures are the same.
Earth	Medium temperature range, includes blackbody temperature	1, 3, 8	Earth's atmosphere lets sunlight through during the day and allows heat to escape during the night. As a result, the day and night temperatures vary somewhat, but they are not extreme. The extremes in the temperature range in the plot are from different locations on the planet, and not the extremes between day and night in one location.

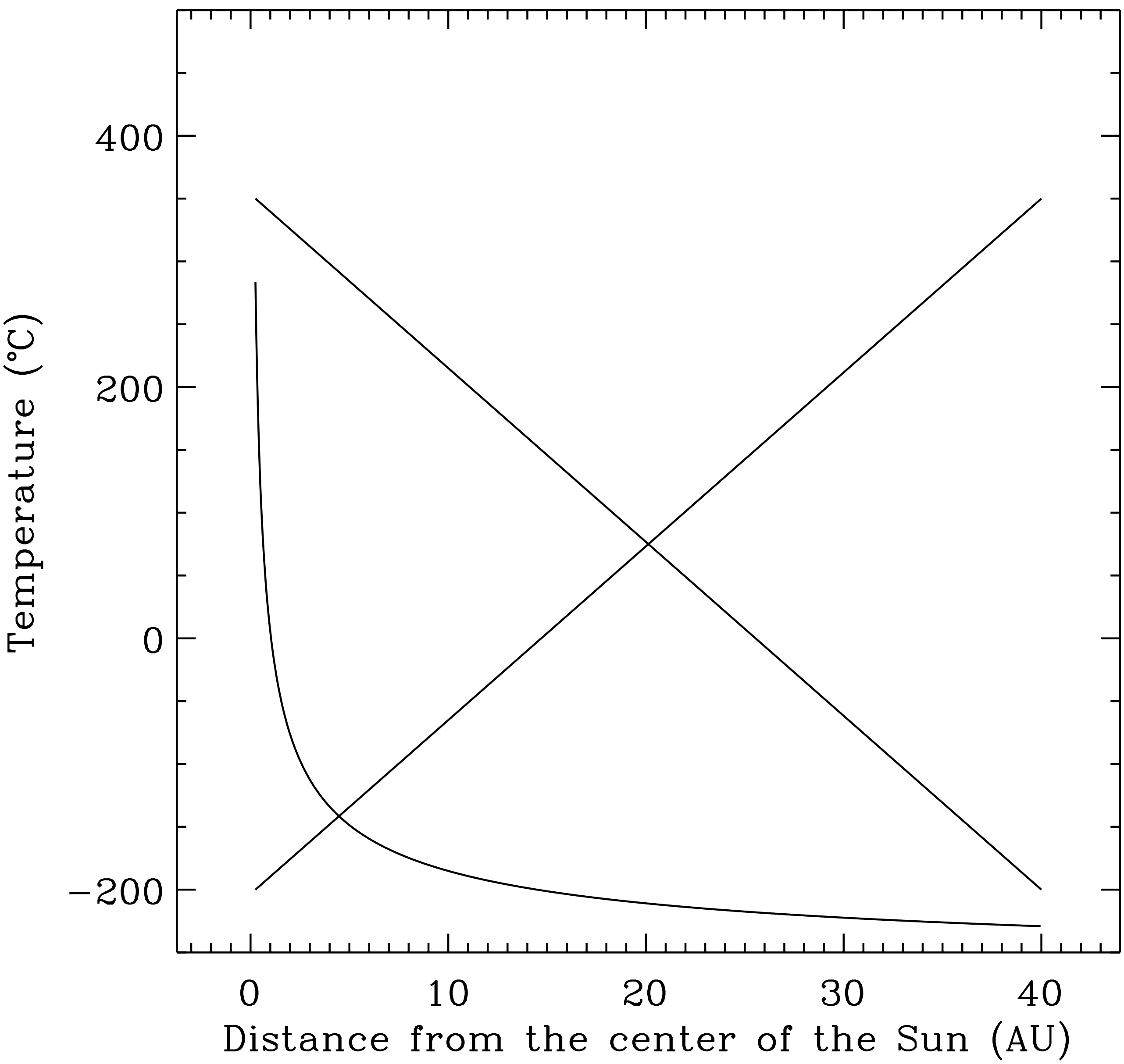
Moon	Larger temperature range than Earth, includes blackbody temperature	1, 5, 8	Even though the Moon and Earth are at the same distance from the Sun, the Moon has minimal atmosphere, and, therefore, temperatures can vary significantly between day and night.
Mars	Medium temperature range, includes blackbody temperature	1, 4, 8	Mars's atmosphere is able to regulate the temperatures somewhat. As a result, the temperatures are different during the day and at night, but the differences are not extreme.
Jupiter	Single temperature, close to blackbody temperature	2, 3, 8, 10	The temperature provided is the average temperature for the cloud tops, and not from a solid surface. Temperatures vary from one cloud formation to another; the temperature provided is the average. Jupiter has a thick atmosphere and an internal heat source.
Europa	Medium temperature range, includes blackbody temperature	2, 5, 8, 12	Europa has minimal atmosphere to moderate temperatures. Tidal heating caused by Jupiter's strong gravity is a significant heat source.
Io	Single temperature, slightly higher than blackbody temperature	2, 5, 8, 12	Io has little to no atmosphere to moderate temperatures. Tidal heating caused by Jupiter's strong gravity is a significant heat source, to the point that there are many volcanoes on Io. The presence of volcanoes keeps temperatures level between day and night.
Ganymede	Medium temperature range, includes blackbody temperature	2, 5, 8, 12	Ganymede has little or no atmosphere to moderate temperatures. Tidal heating caused by Jupiter's strong gravity is a heat source.
Callisto	Medium temperature range, includes blackbody temperature	2, 5, 8, 12	Callisto has little or no atmosphere to moderate temperatures. Tidal heating caused by Jupiter's strong gravity is a heat source.
Saturn	Single temperature, almost equal to blackbody temperature	2, 3, 8, 10	The temperature provided is the average temperature for the cloud tops, and not from a solid surface. Temperatures vary from one cloud formation to another; the temperature provided is the average. Saturn has a thick atmosphere and an internal heat source.
Titan	Single temperature, almost equal to blackbody temperature	2, 3, 8	Titan's thick atmosphere regulates the temperatures and, therefore, day and night temperatures are equal. However, it is so cold at Titan's distance from the Sun that even a greenhouse effect could not raise tempetature much.
Uranus	Single temperature, slightly lower than blackbody temperature	2, 3, 8	The temperature provided is the average temperature for the cloud tops, and not from a solid surface. Temperatures vary from one cloud formation to another; the temperature provided is the average. Uranus has a thick atmosphere but appears not to have an internal heat source.
Neptune	Single temperature, slightly higher than blackbody temperature	2, 3, 8, 10	The temperature provided is the average temperature for the cloud tops, and not from a solid surface. Temperatures vary from one cloud formation to another; the temperature provided is the average. Neptune has a thick atmosphere and an internal heat source.
Pluto	Small temperature range, includes blackbody temperature	2, 4, 8, 16	Pluto has minimal atmosphere to moderate temperatures. More important is the fact that Pluto's distance from the Sun changes a lot during one of its years.

Notes:

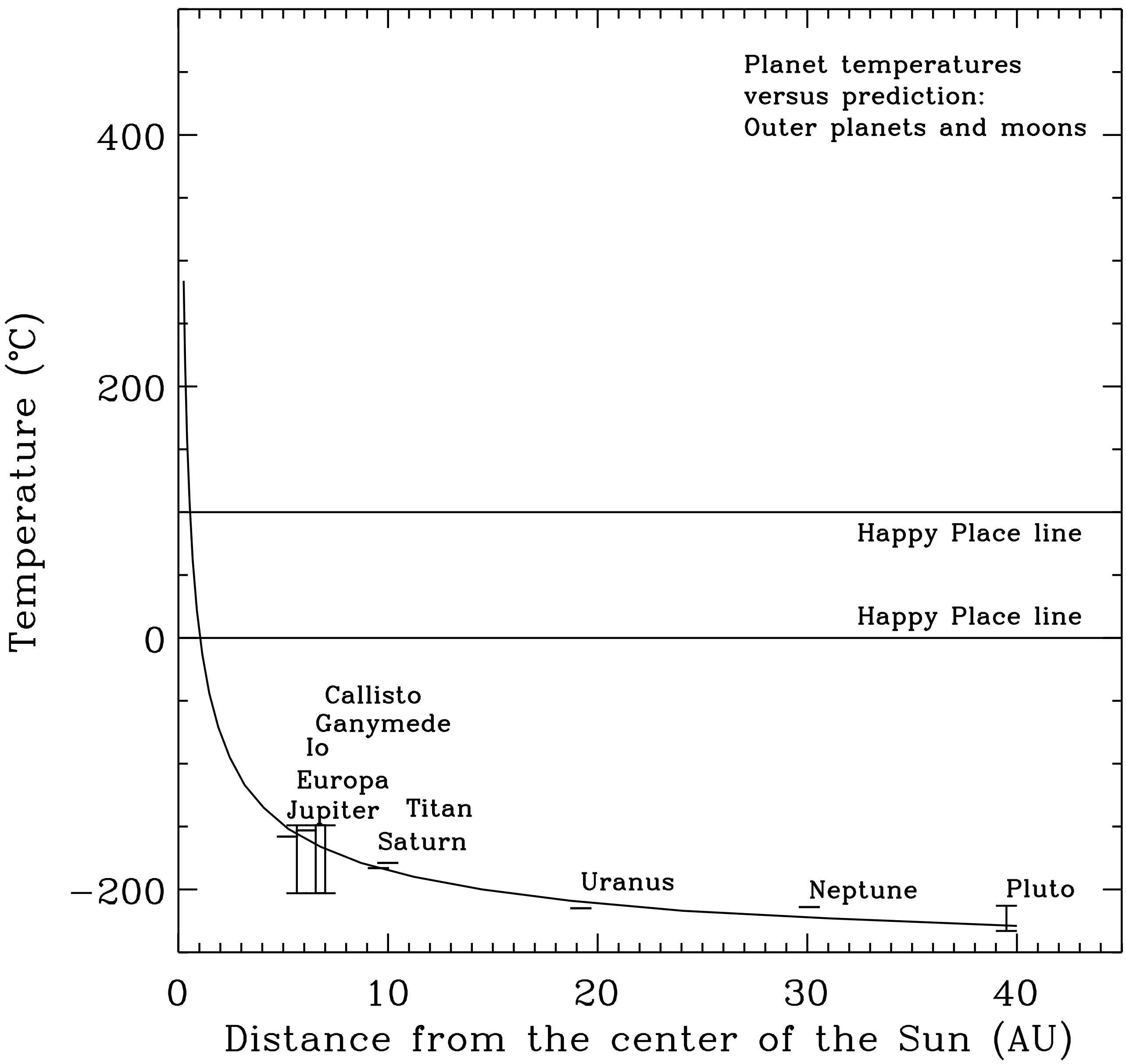
- None of the worlds are perfect blackbodies; planetary albedo allowing less heat to be absorbed—Reason 8—is therefore valid for every world. Even for Venus, the cloudtops reflect some of the sunlight away, but this is counteracted by other effects.
- Reasons 7, 9, 11, 13, 14, 15 in Table 1 are all fake reasons to make sure students do proper research to understand each effect and whether they apply to their world. Make sure that you explain to the students that these reasons are fake.

Student Worksheet 3

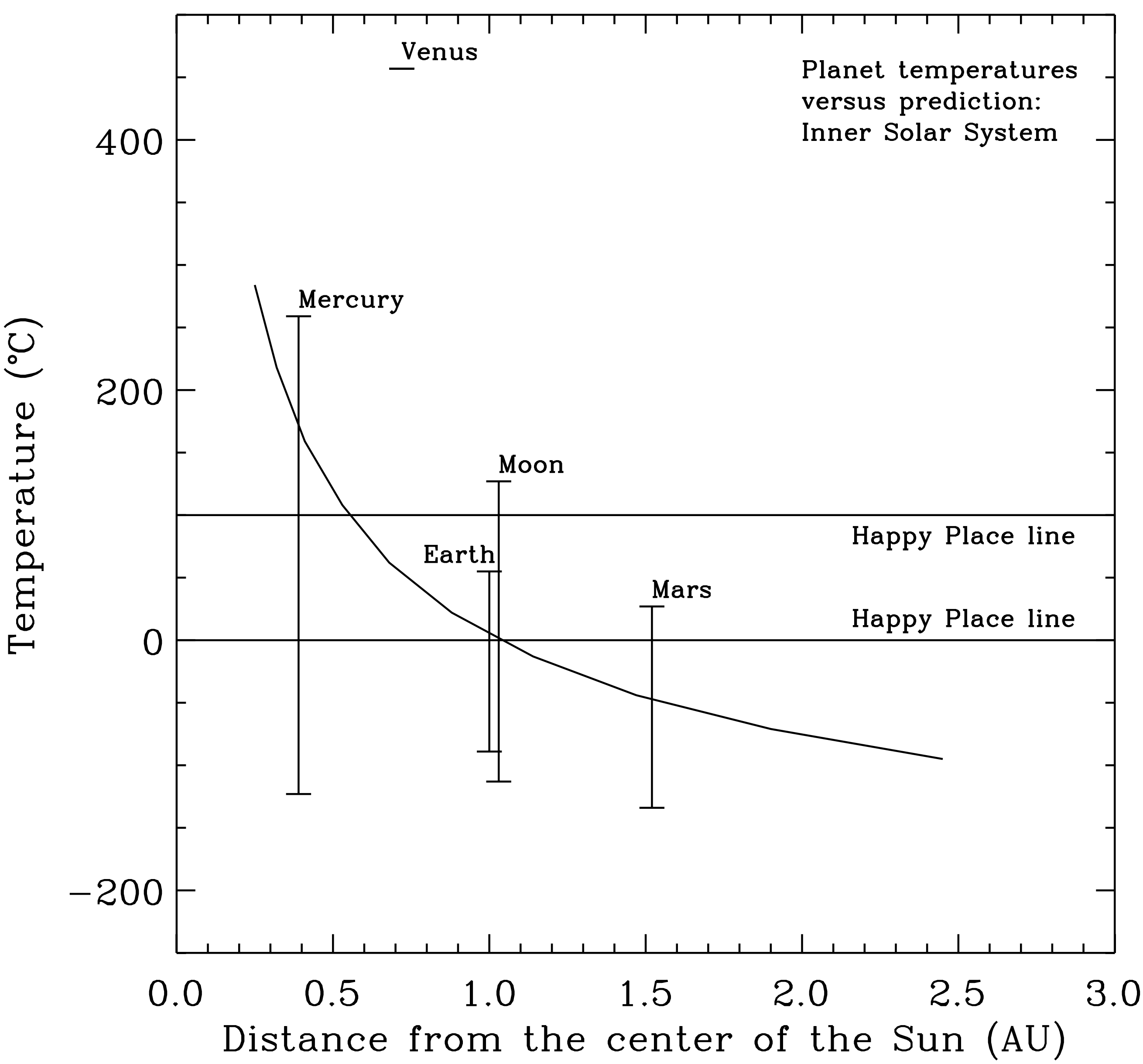
Answers will vary according to students' research. The likeliest places for possible life in the Solar System include Mars, Jupiter's moon Europa, Saturn's moon Titan, and possibly Jupiter's moons Ganymede and Callisto. Finding life anywhere else in the Solar System is unlikely based on our current understanding of what life needs and what the conditions on different worlds in the Solar System are. You can find more details in the *Science Overview*.



Graph A. Possible predictions for the temperature of the blackbody at different distances from the Sun.



Graph 1. Temperatures of the outer planets and moons.



Graph 2. Temperatures in the inner Solar System.

Data Table 1

Distance from the center of the Sun (AU)	Temperature of blackbody (°C)
0.25	284
0.32	218
0.41	159
0.53	108
0.68	62
0.88	22
1.14	-13
1.47	-44
1.90	-71
2.45	-95
3.16	-117
4.07	-135
5.25	-152
6.77	-166
8.72	-179
11.24	-190
14.49	-200
18.68	-209
24.07	-217
31.03	-223
40.00	-229

Data Table 2

	Approximate distance from the center of the Sun (AU)	Temperature range (°C)
Mercury	0.39	-123 to +259
Venus	0.72	+457
Earth	1	-89 to +55
Earth's Moon	1	-113 to +127
Mars	1.52	-134 to +27
Jupiter	5.20	-158 (cloud tops)
Europa	5.20	-203 to -149
Io	5.20	-153
Ganymede	5.20	-203 to -149
Callisto	5.20	-203 to -149
Saturn	9.54	-183 (cloud tops)
Titan	9.54	-179 (surface)
Uranus	19.2	-215 (cloud tops)
Neptune	30.1	-214 (cloud tops)
Pluto	39.5	-233 to -213

Student Worksheet 1: Happy Places

Name ____ Date ___________

Materials

- Data table 1 and 2
- Graph paper
- Colored pencils
- Ruler

Procedure

1. Label the x- and y-axis on two graphs: x is "Distance from the Center of the Sun," and y is "Temperature." The range of temperatures for both graphs will be –250°C to 500°C.

2. Graph 1 will cover the entire solar system out to Pluto. Label this "Graph 1: Outer Planets and Moons."

3. Graph 2 will cover only the inner solar system, as far as mid-way between Mars and Jupiter. Label this "Graph 2: Inner Solar System."

4. Use the "Approximate distance from the center of the Sun" information in Data Table 2 to determine the range for the x-axis for both graphs. Distances from the Sun in this activity are given in AU (Astronomical Units—the average distance from the Earth to the Sun; this is about 150 million km, or 93 million miles).

   What will you use for your x-axis range for Graph 1? ____________

   Graph 2? ____________

5. With a colored pencil, make a curve on Graph 1 predicting the temperature that a blackbody will follow at different distances from the Sun. After you have done this step, stop and wait for your teacher to discuss the curves before going on.

6. Plot the blackbody temperatures using Data Table 1 on both graphs, and connect them with a curved line.

7. How does your prediction compare with what happens to an actual blackbody as it is moved farther from the Sun?

____

____

8. What is the highest temperature at which liquid water can exist under normal conditions (e.g., in the classroom)—the boiling point of water? ______________

9. What is the lowest temperature at which liquid water can exist under normal conditions (e.g., in the classroom)—the freezing point of water? ________________

10. This zone is what we will call the “Happy Place.” Plot the "Happy Place" with a different colored pencil by drawing two horizontal lines (parallel to the x-axis) at the two temperatures from steps 8 and 9.

11. Using the distances (not the temperatures) from Data Table 2, mark a point on the curved blackbody line at the distance of each of the worlds on Data Table 2, labeled by the first letter of the name of each world. Do this on both graphs.

12. Predict which worlds will fall in the "Happy Place."

13. Do you think the worlds in the Solar System behave exactly like blackbodies? Explain your answer.

14. How could we find out?

15. With a different colored pencil, plot the actual temperature ranges of each of the inner planets (through Mars) and the Moon on Graph 2 using the data from Data Table 2. Do the same for the outer planets and their moons on Graph 1. Some of the worlds have two temperatures, which make a temperature *range*. Plot both points and connect them with a vertical line. Some moons and planets should be located in the same place on the graphs. It is okay to put them next to one another so that you can see them all, even though their distances may not be represented accurately this way.

Student Worksheet 2: Why in the World?

Name ____ Date ___________

Select three worlds to research. In the first column, describe the actual temperature on the worlds and its relation to the blackbody prediction. In the second column, choose the best explanation for the relation from Table 1 on page 3 of this worksheet. Describe the significance of this explanation in the third column. Present your results to the class.

World	Description of temperature and relation to blackbody temperature *(Determined by looking at Graph 1 and/or Graph 2)*	Reason(s) for characteristics of the temperature *(Determined by research)* Choose one or more from Table 1	Reason(s) for characteristics of the temperature *(Determined by research)* Describe in your own words
Mercury			
Venus			
Earth			
Moon			
Mars			
Jupiter			
Europa			

World	Description of temperature and relation to blackbody temperature *(Determined by looking at Graph 1 and/or Graph 2)*	Reason(s) for characteristics of the temperature *(Determined by research)* Choose one or more from Table 1	Reason(s) for characteristics of the temperature *(Determined by research)* Describe in your own words
Io			
Ganymede			
Callisto			
Saturn			
Titan			
Uranus			
Neptune			
Pluto			

Table 1. Possible explanations for relation between temperatures on different worlds in the Solar System and blackbody prediction.

1	Receives a lot sunlight
2	Does not receive a lot sunlight
3	Thick atmosphere moderates temperatures very well
4	A thin atmosphere moderates temperatures a little
5	Has little or no atmosphere to moderate temperatures
6	Greenhouse effect traps in heat
7	Greenhouse effect takes away heat
8	Planetary albedo causes less heat to absorb than for a blackbody
9	Planetary albedo causes more heat to absorb than for a blackbody
10	Internal energy source warms the world
11	Internal energy takes heat away from the world
12	Tidal forces heat the world
13	Tidal forces cool the world
14	Heat is taken away from the world by a nearby mysterious space object
15	The world is warmed by a nearby mysterious space object
16	World's distance from the Sun changes a lot during one of its years.

Note: More than one may apply to different worlds.
Note: Some of the reasons listed in Table 1 may be bogus.

Student Worksheet 3: Earth vs. Other Worlds

Name ______________________________ Date ____________

In this activity, you will explore the basic characteristics of Earth that are important for life, and determine how unique they are in our Solar System.

Prepare for research

Select three worlds of the Solar System to study. You can choose a combination of planets and moons. Be sure to pick at least one that you do not know much about.

Research

You can use library and Internet resources to find descriptive characteristics of Earth and each of the worlds you chose to study. Your research must include the four categories important for life: an energy source, a stable environment, protection from radiation, and liquid water. Fill in the table below as you complete your research.

World	Energy Source?	Stable Environment?	Protection from Radiation?	Liquid Water?
Earth				

After completing your research

Prepare a presentation to the class. It must include a comparison between your worlds and Earth using the four categories important for life. Include in your presentation a discussion of whether you found Earth's environment for life to be unique in the Solar System. The presentation can also include a description of what a visitor to these worlds might experience.