JOURNEY through the UNIVERSE

Voyage: A Journey through our Solar System

Grades 5-8

Lesson 8: Comets: Bringers of 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.

Lesson 8: Comets: Bringers of Life?

Lesson at a Glance

Lesson Overview

Comets are an important class of objects found in the Solar System. Created at the time of Solar System formation, these "dirty snowballs"—each the size of a city—have remained virtually unchanged for billions of years in the cold outer reaches of the Solar System. Their composition therefore provides clues as to how the Solar System was born, and comet impacts on the early Earth may have been the source of the molecules needed for the formation of life—organic molecules. In the first Activity, students explore the relative abundance of different atoms in the universe, and the molecules that are created from these atoms. In the second Activity, students combine ingredients composed of these molecules to build a good physical model of a comet. The model provides an understanding of cometary composition and structure, and how comets behave when some make a rare trip into the inner Solar System and interact with the Sun.

Lesson Duration

Two or three 45-minute classes

Core Education Standards

National Science Education Standards

Standard D2: Earth's history

The earth processes we see today, including erosion, movement of lithospheric plates, and changes in atmospheric composition, are similar to those that occurred in the past. Earth history is also influenced by occasional catastrophes, such as the impact of an asteroid or comet.

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 4A4
Many chunks of rock orbit the sun. Those that meet the earth glow and disintegrate from friction as they plunge through the atmosphere—and sometimes impact the ground. Other chunks of rock mixed with ice have long, off-center orbits that carry them close to the sun, where the sun's radiation (of light and particles) boils off frozen materials from their surfaces and pushes it into a long, illuminated tail.

Essential Questions

- What are the components of a comet?
- How are comets important to life on Earth?

Concepts

Students will learn the following concepts:

- We can use models to investigate distant or large objects on a scale that is easily used by humans.
- Comets are made of rock, dust, and ice. The ice changes to gas when a comet comes close to the Sun.
- Comets are made of the same elements and molecules as the rest of the Solar System and are thought to be remnants of the formation of the Solar System.

Objectives

Students will be able to:

- Construct a model of a comet.
- Compare the materials in the model comet to the materials in a real comet.

Science Overview

On a clear night, the sky is filled with twinkling stars. Other objects can be seen, too, such as the Moon or planets. One of the more exciting and rare things to see in the night sky is a comet, which appears as a fuzzy ball of light with a misty tail stretching out from it.

Comets as Omens

Before the true nature of comets was understood, these spectcacular objects often evoked fear and anxiety in those who observed them. Creative explanations for these lights in the sky were developed, and they were considered to be omens of war, famine, or even signs of the death of a ruler.

The physical appearance of comets also conjured up some interesting descriptions. Halley's Comet, which approached Earth in the year 66 C.E., was described as a sword that hung over Jerusalem. Others felt that the tails of comets suggested long, flowing hair. In fact, the word "comet" comes from the Greek word, "cometes," which means "long-haired."

Great strides were made in appreciating the true nature of comets when, in 1577, Danish astronomer Tycho Brahe (1546-1601) showed that comets were independent members of the Solar System. Prior to his time, most people believed that comets were phenomena of the Earth's atmosphere. Brahe used observations and a little bit of geometry to explain how comets must be located far away from Earth—at least farther away than the Moon.

Today, scientists look upon comets as a source of information about our Solar System. Comets are thought to be remnants of the formation of the planets, making them some of the oldest unaltered objects in the Solar System. Therefore, understanding more about comets will increase dramatically our understanding of the early years of the Solar System. Because of this, there are many robotic space missions slated to investigate a sampling of comets in the next few years.

The Home of the Comets

Many comets come from an area in the Solar System beyond the orbit of Neptune called the Kuiper Belt. Objects in this region—called Kuiper Belt Objects or sometimes Trans-Neptunian Objects—are so far away and so small and dark that astronomers have a hard time detecting them. The Kuiper Belt is located 30-50 AU away from the Sun. (One AU = one astronomical unit, or the average distance between the Earth and the Sun; 150 million km or 93 million miles. For comparison, Neptune, the farthest planet from the Sun, is located at 30 AU.) The Kuiper Belt is where short-period comets, or comets that take less than 200 years to orbit the Sun, originate. It is not certain exactly how some Kuiper Belt Objects become comets, but one possibility is that, on occasion, an object in the Kuiper Belt comes to feel the gravitational nudge of the giant planets and, as a result, drifts into a new orbit that sends it to the inner parts of the Solar System to become a short-period comet.

Most comets, however, reside in the Oort Cloud which begins well past the planetary realm of the Solar System and continues halfway to the nearest star, to a distance of about 100,000 AU. Unlike the Kuiper Belt, whose objects orbit the Sun in a region that is shaped much like a disk, the Oort Cloud is believed to be a spherical shell of cometary bodies. No one has been able to see a comet while it is in the Oort Cloud, but the orbits of observed comets suggest that the Cloud is there and contains about one trillion comets. Sometimes a gravitational disturbance (such as a passing star or an interstellar nebula) causes one of these bodies to change its orbit and begin the long journey toward the inner Solar System. The comets that come from the Oort Cloud are long-period comets; their orbit around the Sun takes longer than 200 years, and in some cases millions of years are needed. Many of these comets are ejected from the Solar System and do not return at all.

Composition

The objects that reside in the Kuiper Belt and Oort Cloud are not the spectacular comets that are seen when they come to the inner Solar System. They are made of water, carbon dioxide, ammonia, and methane ices, as well as rock, dust, and organic (carbon-based) substances. They have been described as "dirty snowballs," a description that Harvard astronomer Fred Whipple (1906-2004) came up with in 1950. The main part of the comet is called the nucleus. They are usually a few kilometers across and are darker than charcoal. This is the form of the comets during most of their orbit around the Sun, and in the outer Solar System, it is the only part of the comet.

When a comet's orbit brings it nearer to the Sun, its ices begin to sublimate: change directly from solid to gas. This forms a cloud of gas and dust particles around the nucleus called the coma. The coma's size depends on the comet's distance from the Sun, and when a comet approaches perihelion (its closest approach to the Sun), the coma becomes as big as the Earth, and can even reach the size of the Sun!

The solar wind—a stream of fast-moving particles flowing from the Sun—and radiation pressure—pressure exerted by sunlight—push the coma particles away from the nucleus, forming the third component of the comet, its tail. It is not unusual for the tails of comets to extend more than 1 AU. Because the tail is formed by forces coming from the Sun, it always points away from the Sun. Therefore, the tail follows the nucleus on the comet's way into the inner Solar System, but leads on the way out. This is similar to a windsock, which always points away from the direction from which the wind is coming. The different particles of the tail are accelerated away from the comet's head (nucleus and coma) at different rates, due to their different sizes and properties. Often, the result is two tails: one made of the gas particles, and one made of the dust particles. The gas tail is accelerated almost straight out from the Sun by the solar wind. The dust tail is created by radiation pressure and can appear to be slightly curved with respect to the direction to the Sun.

Figure 1. Comet Hale-Bopp in 1997.
(Picture credit: http://antwrp.gsfc.nasa.gov/apod/ap001227.html)

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Origin of Comets

The Solar System was formed about 4.6 billion years ago from a cloud of gas and dust. This cloud was made of the most abundant elements in the Universe, mostly hydrogen (93.4%) and helium (6.5%), with all the other elements (often called "heavy elements") making up the remaining 0.1%. The elements were combined in the cloud to form molecules such as molecular hydrogen, carbon monoxide, and ammonia, which is why these clouds are often referred to as molecular clouds. Most of the molecules in molecular clouds are a combination of hydrogen and the most common heavy elements, carbon, nitrogen and oxygen. Helium is a so-called noble gas and does not combine with other elements to form molecules. Since the Solar System was formed inside a molecular cloud, these most common elements and molecules in the Solar System are the same as in molecular clouds (and the rest of the Universe). The Sun and the giant planets (such as Jupiter) are mostly made of hydrogen and helium. The gravity of smaller objects in the Solar System could not hold onto the light elements such as hydrogen and helium as well as the more massive objects, and the smaller bodies are mostly made of heavy elements (and of hydrogen that had combined with other elements.) Almost all of the mass on Earth is made of the heavy elements, the 0.1% of the cloud material, as are comets.

Comets are thought to be some of the oldest, most primitive objects in the Solar System. They are thought to have served as building blocks in the formation of planets. Most objects in the Solar System have changed dramatically since their formation, mostly due to the heat from the Sun and impacts among the Solar System objects. Comets are thought to be remnants from the formation era of the Solar System, preserved by their great distance from the Sun.

Comets and Life

One of the events that has had the most powerful impact on Earth's evolution as a planet was the emergence of life. Exactly how this occurred remains a mystery, although scientists have offered numerous hypotheses. One of the more promising suggests that life was generated from a "primordial soup": a warm, moist pool of molecules that interacted with a primitive atmosphere and was subjected to some sort of energy source, such as lightning. An experiment performed by Stanley Miller (1930-2007) and Harold Urey (1893-1981) at the University of Chicago in 1953 generated amino acids and organic molecules by simulating the conditions on early Earth. The result was very interesting, because amino acids are much more complex than the original ingredients, and are fundamental elements of life. Although this demonstration is still a far cry from producing a living being, it was an encouraging step toward understanding life's beginnings.

It is debated, however, as to how the materials that are integral to the chemistry of life could survive conditions on the early Earth. Earth is thought to have been in a molten state soon after its formation. As a result, even if volatiles (such as water) and organic molecules had been present during Earth's formation, it might have been difficult for enough of them to survive to form the extensive oceans and life forms on Earth today. Scientists have suggested that comets played an important role in bringing water and organic materials necessary for life back into the hot primordial inner Solar System, in which the Earth was formed. The cometary materials had not been subjected to the harsh environment that the Earth had, since they were preserved in the cold reaches of the outer Solar System.

Comets could have brought the water and organic molecules to Earth in two ways. Comets lose as much as one percent of their material during every trip to the inner Solar System, and some of this material gets left behind in their orbits. Earth sweeps through the comets' orbits and collects their materials. The other way comets could bring materials to planets is through direct impacts. A comet the size of Comet Halley would bring enough water to Earth to form a large lake. Some scientists suggest that the oceans formed primarily from cometary impacts.

Impacts on Planets

When a comet impacts a planet or another body in the Solar System, it may cause major changes in it, depending on the size of the comet as well as the size of the object the comet impacts. Earth appears to have undergone many catastrophic impacts in the past that have changed the course of life on Earth. Some of these impacts were due to comets, but some were caused by asteroids, which are small bodies similar to comets, except that asteroids are made of rocks, instead of a mixture of rock and ices, and they tend to reside in the inner part of the Solar System, especially in a region of space between the orbits of Mars and Jupiter called the Asteroid Belt. There are two reasons that scientists can prove that comets (and asteroids) have impacted planets. First, there are craters on planets, even on Earth. The landscape of the cratered Moon was formed by many years of impacts by comets and asteroids. Second, scientists have actually witnessed such an impact!

In 1994, comet Shoemaker-Levy 9 crashed into Jupiter, creating disturbances in the planet's atmosphere that were visible for months afterwards. The comet's orbit had been disturbed when it got too close to Jupiter to resist its gravitational pull. In fact, the pull was so strong that the comet was split into at least 21 discernible fragments two years before it plunged into Jupiter's atmosphere. The largest of these fragments was 4 km (2.5 miles) in diameter, and upon arrival produced an explosion the equivalent of 6,000,000 megatons of TNT, or about 75 times the estimated nuclear arsenal of the entire world during the height of the Cold War. This was the first time scientists were able to witness such a collision in the Solar System, and as many available instruments on Earth and in space (Hubble Space Telescope, Galileo spacecraft) as possible were used to capture images of this amazing event.

There is evidence that Earth has been hit by comets and asteroids, as well. Although the atmosphere prevents small bits from making craters on Earth, large ones can make it through and create impact craters many kilometers wide. An example of such an impact crater is the Meteor Crater in Arizona, which has become a tourist attraction in the southwestern U.S. Impact craters are even found under the oceans.

Comets have played quite a role in shaping the development of Earth into what it is today. They are thought to be the link to the formation of the Solar System, as well as the bringers of water and other materials that are necessary for life (and perhaps even life itself) into the inner Solar System. For this reason, comets are sometimes referred to as "bringers of life." Also for these reasons, and many more, scientists want to study comets to gather information that may shed light on the early years of the Solar System.

Spacecraft Missions to Comets

The first spacecraft to study a comet was NASA's International Comet Explorer, which flew by the comet Giacobini-Zinner in 1985. The following year, five robotic spacecraft from around the world flew by the Comet Halley as it reached perihelion. The most well-known of these was European Space Agency's Giotto, which obtained close-up photographs of the comet's nucleus, revealing that it is made of darker material than previously thought.

More closeup studies have been performed recently. In 2005, a 350 kg (770 lb) impactor released by NASA's Deep Impact spacecraft collided with Comet Tempel 1 and blasted out a crater. This made it possible to study the interior of the comet, as well as the material that was blasted off. The Stardust spacecraft encountered Comet Wild 2 in 2004, gathered dust from the comet, and brought the samples back to Earth for laboratory studies in 2006. These missions, as well as new ones that are currently underway or being planned, help scientists form a better understanding of the formation of the Solar System and how comets may have impacted its later evolution.

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Conducting the Lesson

Warm-Up & Pre-Assessment

Student Materials

- Student Worksheet 1

Preparation & Procedures

Hand out copies of Student Worksheet 1. Have students complete the worksheet, and encourage them to draw illustrations to go with their answers. You can use students' answers as an informal method to assess prior knowledge and to start a class discussion. Students' answers will vary. Here are some suggestions of where to lead the discussion.

Examples of Student Responses	**Discussion Points**
A comet is a big rock.	The parts of a comet.
A comet is like a small planet.	The differences between comets and planets.
We should study comets because one might hit the Earth.	Impacts, craters, and their effect on life on Earth.
Comets and asteroids are made of different material.	The differences between comets and asteroids.

Teaching Tip

You may want to read the *Science Overview* prior to this discussion if you are not familiar with comets.

NOTES:

Activity 1: A Handful of the Universe

Students will use a model of the composition of the universe to determine the relative abundance of different atoms. Students then explore which molecules can be created from these atoms.

Teacher Materials

- 9 copies of Materials of the Universe Sheet 1 (located in the back of the lesson)
- 1 copy of Materials of the Universe Sheet 2 (located n the back of the lesson)
- Paper cutter or scissors
- Cardboard box (shoebox size or larger)
- Black construction paper (enough to cover the box)
- Marker to label the box (white or silver)
- Blackboard or white board

Preparation & Procedures

1. Before class, make 9 copies of the Materials of the Universe Sheet 1, and 1 copy of the Materials of the Universe Sheet 2. Cut out the pieces so that you have a total of 1,000 pieces (one element symbol per piece). Place these in a cardboard box with a hole on the top so that students can reach into the box. Cover the box with black construction paper—but remember to leave the hole on top uncovered—and label the box "Universe" with a white or silver marker.

2. In order to figure out what comets are made of, it is important to understand what the Universe is made of. Discuss the concept of an element. You can use the following facilitation:

   Tell your students to pretend that you have a chunk of iron in your hand. Ask them what will happen if you cut the chunk in half. (*Desired answer: you will have two chunks of iron.*) Ask what would happen if you threw one piece away and cut the other piece in half again. What would happen if you did this again and again? (*Desired answer: you would get smaller and smaller pieces until you got to a point where you could not cut it in half anymore*) What is the smallest piece of iron you can have before it is no longer iron? (*Desired answer: one atom of iron*) What do we call substances in which there is only one kind of atom? (*Desired answer: elements*)

Teaching Tip

If your students are not familiar with chemistry and the periodic table, be sure that a periodic table of the elements is within eyesight. If they are expected to know the elements already, make sure there is not one in plain view.

How many types of elements are there? (*Desired answer: about 114; be sure to check your most current periodic table for new discoveries.*)

3. Ask the students to name the most abundant elements in the Universe. Take a few suggestions, and then tell them that you have a representative sample of the Universe in your black box. Have the class line up and come reach into the box and pull out a sample "handful of the Universe." Make sure every student gets to reach into the box. If there are leftovers, keep them as your own sample.

4. Survey the class results. Have each student count their "atoms." Ask the students to tell you the name of the most abundant atoms in their sample. Since most are hydrogen, go through the class, one by one, and tally the number of atoms they have that are not hydrogen. Have the students calculate how many hydrogen atoms there are (assuming there are a total of 1,000 pieces), and the percentage of each element in the "Universe." They should be able to fill in a table like the one below:

TEACHING TIP

Divide 1,000 by the number of students in your class; that is how many pieces of paper each student should pull out. So that one student does not end up with half of the pieces, or so that students are not left out, hold up a sample of the desired number of pieces and tell them to pull out a handful of Universe about that size.

Element	Total atoms	% of all
Hydrogen		
Helium		
Other		

Reflection & Discussion

Ask the students the following questions:

1. What do you notice is the most abundant element? Why do you think this is? (*Desired answer: hydrogen; it is the simplest, made of only one proton and one electron*)

2. What is included in "All Other Elements?" (*Desired answer: every element on the periodic table other than hydrogen and helium*)

3. What is the Earth made of? (*Desired answer: almost everything on Earth, including the students themselves, is made of "All Other Elements" or at least molecules consisting of them*) If hydrogen is the most abundant element, then why isn't the Earth made almost entirely of hydrogen? (*Desired answer: hydrogen is too light for Earth's gravity to hold on to it. Some of the more massive planets, like Jupiter, can "grab" onto hydrogen, but Earth can only hold onto hydrogen if it is part of a heavier molecule, such as water.*)

4. What are the most abundant elements in the group "All Other Elements"? (*Desired answer: three of the most common are carbon, oxygen, and nitrogen*)

5. Do you think this is representative of the Universe? Do the elements always stand alone? What is it called when atoms interact? (*Desired answer: chemistry*) When atoms combine, what do we call the results? (*Desired answer: molecules*) Since hydrogen is most common, it makes sense that molecules with hydrogen will be common. The most common molecule in the Universe would therefore be molecular hydrogen—H_2. What other molecules are made when common elements—such as hydrogen, and the most common of the heavy elements, carbon (C), nitrogen (N), and oxygen (O) combine? If the students have some background in chemistry, they should come up with the following elements: H_2O (water), CO_2 (carbon dioxide), NH_3 (ammonia), and CH_4 (methane). You can also advise the students to consult chemistry-related Web sites or reference books and see which molecules one could make with the most common elements in the Universe. You may also want to point out to the students that helium, being a noble gas, does not form molecules with other elements, even though it is the second most common element.

Transfer of Knowledge

On the back of Student Worksheet 1, have students write what they think comets are made of, based on their discussion of the most abundant materials in the Universe. (*Desired answer: comets are made of the same materials, because there is no reason to think they are nothing but good samples of the average composition of the Universe. See* Science Overview *for a description how the most common elements in the Universe end up in comets the way that they do.*)

Placing the Activity Within the Lesson

As discussed in the Activity, the most abundant elements in the Universe form molecules. In space, the molecules can form into molecular clouds, within which stars are born. About 4.6 billion years ago, the Solar System was born from such a molecular cloud. Discuss this process with the students, and come to the conclusion that everything in the Solar System, including Earth and the students themselves, formed from what once was a molecular cloud. Therefore, the Solar System was originally made from the same molecules that were in the molecular cloud. Over time, conditions in the inner Solar System have changed a lot because of the heating from the Sun, while conditions in the outer parts of the Solar System have changed less. Tell students that, in the next activity, they will investigate how things might be different if they were to "grab a handful" of different locations in the Solar System, particularly in the outer edges of the Solar System where it is very cold.

Assessment Criteria for Activity 1

5 Points

- Student participated in the activity.
- Student attempted to make the connection between the materials in the Universe and the materials in a comet.
- Student made the correct connection between the materials in the Universe and the materials in a comet.
- Student attempted to explain why the materials in a comet are the same as the materials in the Universe.
- Student explained correctly why the materials in a comet are the same as the materials in the Universe.

4 Points

- Four of the five criteria above are met.

3 Points

- Three of the five criteria above are met.

2 Points

- Two of the five criteria above are met.

1 Point

- One of the five criteria above is met.

0 Points

- No work completed.

Notes on Activity 1:

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Activity 1: A Handful of the Universe

Activity 2: Cookin' Up a Comet

Lesson Wrap-Up

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Activity 2: Cookin' Up a Comet

Students will create a physical model of a comet from ingredients representing the molecular composition of the cloud from which the Solar System was born—the solar nebula. The model will provide an understanding of cometary composition and structure, and how comets behave when they interact with the Sun.

Teacher Materials

- Protective eye goggles
- Heavy dishwashing gloves
- Overhead projector
- Hair dryer
- Plastic wrap (enough to cover the glass top of the overhead projector)
- Hammer or mallet
- Large metal tub (at least 20 liters—5 gallons—in capacity)

Student Materials
(per group of 3 unless otherwise specified)

- Student Worksheet 2 (per student)
- Measuring cup (at least 240 ml—1 cup—capacity)
- 3 cups of water
- A few drops of sudsing ammonia
- A handful of sand
- A splash of cola
- Large wide mixing bowl
- Large wooden or plastic spoon for stirring
- Heavy dishwashing gloves (2 pairs per group)
- Protective eye goggles (1 pair per student)
- Newspaper (enough to cover work surface)
- 2.5 cups dry ice (about 10 lbs. needed for a class of 30 students)

Preparation & Procedures

1. Purchase dry ice (frozen carbon dioxide; CO_2) from an ice company or an ice cream parlor the day of or evening prior to conducting Activity 2. If possible, get the pellet form of dry ice (rather than the block form); it is easier to crush. However, be aware that the pellet form will sublimate and disappear more quickly than the block form. Be sure to purchase at least ten pounds of dry ice; more will be needed if purchased the evening before. (Ten pounds of dry ice

TEACHING TIP

You can set up the materials in two ways. You could put the ingredients at each student work station. If you do not have enough materials to give every group their own set-up, you can have all of the materials located in one place, and give the students plastic cups to transport the ingredients to their work stations. When it is time for students to add the dry ice, you could have them bring their bowl to where the dry ice is located, and add it directly to their mixture.

will sublimate in 24 hours unless kept in an insulated bin. Depending on the level of insulation, dry ice storage bins will lose 2%—10% of the dry ice per day.) You may also want to get extra for a test run the night before.

2. Store the dry ice in an ice chest. Place an inch or so of newspaper between the dry ice and the container to prevent the container from cracking. Remember to wear rubber gloves when handling dry ice.

3. Put on protective eye goggles and rubber gloves. Using a hammer, crush the dry ice pellets or blocks in a large metal tub to the consistency of snow. You can do this before the students arrive to class to save class time.

DO NOT HANDLE DRY ICE WITHOUT PROTECTIVE GLOVES!!

4. Set up the classroom so that there are enough stations for each group of three to have their own space. The groups will need a large table or a few desks pushed together. To protect the desks, each station should be covered with newspapers.

5. Discuss with students why comets are thought to be remnants of the formation of the Solar System. You can use the following facilitation: Ask the students how we keep things from spoiling or melting. (*Desired answer: we put them in a refrigerator*) What if we want to keep them even longer? (*Desired answer: we put them in a freezer*) The colder something is, the longer it keeps from spoiling. Ask students where comets originate. (*Desired answer: in the outer parts of the Solar System*) What is the temperature like there? (*Desired answer: it is very cold so far from the Sun*) Now that you have drawn the parallel between keeping things from spoiling and a comet's environment, ask the students why they think comets are considered to be leftovers from the formation of the Solar System. (*Desired answer: comets were preserved in their cold environment*) Explain that by studying comets, we can study the conditions in the early Solar System.

6. Review with the students the structure of a comet: nucleus, coma, and tail. Discuss the composition of a comet nucleus (dirt, dust, water ice, carbon dioxide ice, methane ice, ammonia ice, and organic molecules). One way comets can be studied in the classroom is by making a model.

7. Divide students into groups of three, and designate the following jobs in each group: Chef, Ingredients Expert, and Recorder.

8. Have students make a model of the comet following the procedures on Student Worksheet 2.

9. When the model comets have been made, cover an overhead projector with plastic wrap. Place a volunteer group's comet on the plastic wrap and turn on the overhead projector. The whole class can look at the projection on the wall or screen and see gas appearing to come from the comet. Ask the students what is happening when dry ice is giving off gas. (*Desired answer: dry ice is sublimating*) Ask why this is happening. (*Desired answer: surrounding air is much warmer than the dry ice, and the dry ice turns right from solid to gas*) Point out that what they are actually seeing is not the sublimated carbon dioxide gas (which is invisible by itself), but water vapor that is condensing as the cold carbon dioxide cools the surrounding air. Now turn on a hair dryer, set on low, and blow warm air on the comet nucleus. Ask the students what they see, and what part of a real comet it represents. (*Desired answer: gas blows away from the model; a tail*) Ask them what they think the hair dryer represents. (*Desired answer: the Sun*) Ask the students if the hair dryer represents the Sun, which way is the comet moving? (*Desired answer: You cannot tell. The tail is caused by solar wind and radiation pressure from the Sun, and will look the same no matter which direction the comet is traveling*) Point out to the students that this is not an exact model for how a comet's tail forms—it is physically different because there is no blowing air coming from the Sun. This is, however, a good way for students to remember that comets' tails always point away from the Sun. (See the *Science Overview* for a more detailed explanation of how comets' tails form.)

Reflection & Discussion

1. Ask the students what they know about the formation of the Solar System. Discuss how the Sun, planets, and other Solar System objects formed from the same molecular cloud. Ask them which elements and molecules they think would have made up the cloud. (*Desired answer: remind them of Activity 1; it would be made of the same materials that make up the Universe*) Ask the students why these molecules are important. (*Desired answer: among other things, they are necessary for life*)

2. Discuss how some scientists think that water and organic materials were brought to Earth by comets. Ask students: if all the objects in the Solar System were formed out of the same molecular cloud, then why were the molecules needed for life on comets, and not on Earth? (*Desired answer: originally, they were everywhere. Earth went through a very hot phase during its formation and all or most of its water and organic molecules may have been destroyed.*) If students cannot think of this answer, prompt them by reminding them of your previous discussion: Why do we keep things in the refrigerator? Were the objects in the inner Solar System cool when they were forming?

3. Discuss with the students how we know what comets are made of if human beings have never visited one. Explain that scientists have studied the spectrum of light coming from real comets' comas and tails to determine the presence of these substances. The research carried out by the many robotic spacecraft that have investigated comets closeup (see the *Science Overview* and the web sites listed in the *Internet Resources & References* section for more details) have provided further data on the composition of comets.

Transfer of Knowledge

Allow students to rewrite their answers in the column labeled "Significance" in the Ingredients Chart on Page 3 of Student Worksheet 2. Based on your class discussion, students should be able to infer the significance of each comet component.

Assessment Criteria for Activity 2

5 Points

- Student did all that his or her Team Role required.
- Student accurately completed the table on Page 3 of Student Worksheet 2, including the "Significance" column.

4 Points

- Student did all that his or her Team Role required.
- Student accurately completed the table on Page 3 of Student Worksheet 2, including most of the "Significance" column.

3 Points

- Student did most of what his or her Team Role required.
- Student accurately completed most of the table on Page 3 of Student Worksheet 2, including most of the "Significance" column.

2 Points

- Student did most of what his or her Team Role required.
- Student accurately completed most of the table on Page 3 of Student Worksheet 2, including some the "Significance" column.

1 Point

- Student did some of what his or her Team Role required.
- Student accurately completed some of the table on Page 3 of Student Worksheet 2, including some of the "Significance" column.

0 Points

- No work completed.

Extensions

- Choose some other object, system, or phenomenon, and ask your students to write a plan for how they would model it. How do models help us understand the world we live in?
- Research how solar wind and radiation pressure affect comets, causing two tails to form.

Placing the Activity Within the Lesson

Ask the students of which elements and molecules we humans are made. They are the same elements and molecules that make up comets. After you discuss with the students the idea that comets introduced volatiles and organic molecules to the inner Solar System, ask them if there are other ways in which comets have affected the formation and development of the planets. (*Desired answer: impacts; see* Science Overview *for examples*)

Notes on Activity 2:

Lesson Wrap-Up

Lesson Closure

Ask the students how they think comets were able to bring organic and volatile materials to the inner Solar System. (*Desired answer: Materials are ejected from comets as they come close to the Sun, and are left in space. As a planet travels through these regions, the materials can fall onto the planet's surface. Comets could have also brought these materials to Earth through direct impacts.*)

Transfer of Knowledge for the Lesson

Have students write an essay explaining the statement, "Comets are bringers of life." Have them use examples from what they have learned in this lesson to support their explanation, and do any additional research necessary to support their essay.

Suggestions for a complete essay:

- Comets bring organic molecules to the inner Solar System.
- Comets bring water and other volatiles to the inner Solar System.
- These materials are needed for life.
- As comets sublimate, they leave these materials in their orbit, which Earth sweeps up as it moves through these regions.
- Comets may have impacted Earth in the past, bringing these materials.
- Earth may have lost most or all of these materials during a very hot phase in its evolution, and comets could have re-introduced them.

Assessment Criteria for the Lesson

After the lesson, have students answer the questions again in Student Worksheet 1, and compare the two worksheets to assess improvement.

5 Points
- Student answered questions in Student Worksheet 1 thoughtfully before the lesson.
- Student improved his/her understanding of questions in Student Worksheet 1 after conducting the lesson.
- Student's essay in *Transfer of Knowledge for the Lesson* explained why comets are considered bringers of life accurately.
- Student's essay in *Transfer of Knowledge for the Lesson* provided evidence as to why comets are considered bringers of life.
- Student's essay in *Transfer of Knowledge for the Lesson* was coherent and demonstrated age-appropriate writing skills.

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.

Extensions for the Lesson

- Place students into groups of four, and have each group use Student Worksheet 3 to study one of the following famous comets: Comet Hale-Bopp, Comet Halley, Comet West, Comet Shoemaker-Levy 9, Comet Tempel-Tuttle, Comet Enke, Comet Wild 2.
- Have students research a cometary mission, such as Stardust or Deep Impact, and how it has helped us learn more about the composition of comets. Students could also research the use of Aerogel on the Stardust mission and how this revolutionary material made the mission possible.
- Have the students research the effect of cometary impacts on the life on Earth, including the idea that impacts have caused mass extinctions in Earth's history, such as the extinction of the dinosaurs.

Curriculum Connections

Social Studies: Research the history of comets. Are they really signs of doom? For example, have students research the role Halley's Comet played at The Battle of Hastings in 1066. The story of the battle is told through the Bayeux Tapestry.

Language Arts: Write a story from the perspective of a comet. What type of things would you see in the Solar System? How would space feel? Use as many adjectives as possible.

Art: Students can draw pictures of comets or use other materials to build models. They can draw the comet from different angles, distances, etc.

Art History: Research how comets have been portrayed in art through the ages.

Lesson Adaptations

Special Education

Provide students more time for the warm-up and discussion about comets. It is necessary that students understand the nature of comets before moving on to the activities.

You can do Activity 2 as a demonstration and have students fill out the worksheet as you add the ingredients into your model comet.

NOTES:

Comets:
Bringers of Life?

Lesson at a Glance

Science Overview

Conducting the Lesson

Warm Up & Pre-Assessment

Activity 1: A Handful of the Universe

Activity 2: Cookin' Up a Comet

Lesson Wrap-Up

Resources

Resources

Internet Resources & References

Student-Friendly Web Sites:

KidsAstronomy.com Solar System
www.kidsastronomy.com/solar_system.htm

Online Explorations
amazing-space.stsci.edu/resources/explorations/

Periodic Table of Elements at Los Alamos National Laboratory
periodic.lanl.gov/

Teacher-Oriented Web Sites:

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

Comet Hale-Bopp
www.jpl.nasa.gov/comet/

Comet Halley
www.nineplanets.org/halley.html

Comet Shoemaker-Levy 9
www2.jpl.nasa.gov/sl9/

Deep Impact Mission
solarsystem.nasa.gov/deepimpact

NASA Solar System Exploration Comets Page
solarsystem.nasa.gov/planets/profile.cfm?Object=Comets

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

National Space Science Data Collection: Asteroid and Comet page
nssdc.gsfc.nasa.gov/planetary/planets/asteroidpage.html

Nine Planets Comets Page:
www.nineplanets.org/comets.html

Periodic Table of Elements at Los Alamos National Laboratory
periodic.lanl.gov/

Stardust Mission
stardust.jpl.nasa.gov/

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

Journey through the Universe
www.journeythroughtheuniverse.org

Teacher Answer Key

Student Worksheet 2

Model Ingredient	Corresponding Comet Ingredient	Same? If not, why not?	Chemical Formula (or elements involved)	Significance?
Water	Water (ice)	Yes (as ice in a real comet)	H_2O	Water is necessary for life
Sand	Dust, rock	Not exactly – there are other rocky materials in comets besides sand. But sand is a good representation of them all	Silicates (silicon, oxygen, and other elements)	Same materials that make up the terrestrial planets; creates comet's dust tail
Ammonia	Ammonia ice	Yes (But since it needs to be very cold to have ammonia ice, an ammonia solution is used in the model)	NH_3	Indicates that comets originate in a region where it is VERY cold
Cola	Organic materials	Not exactly; cola has organic materials like sugar and so can represent all these materials, but there is no actual cola in a real comet	Carbon compounds	Organic materials are necessary for life
Dry Ice	Carbon dioxide	Yes	CO_2	One of the gases that creates the comet's gas tail when the comet approaches the Sun

Sheet 1
(make 9 copies)

H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H

Materials of the Universe

Sheet 2
(make 1 copy)

H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	H	H	H	H	H	H
H	H	H	H	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	He
He	He	He	He	He	He	He	He	He	All Other Elements

Student Worksheet 1:
Warm-Up & Pre-Assessment

Name ______________________________ Date ____________

A comet is...

____

____

____

____

A comet looks like...

____

____

____

____

We should study comets because...

____

____

____

____

A comet is different from an asteroid because...

____

____

____

____

Student Worksheet 2:
Cookin' Up a Comet

Name ______________________________ Date __________

Your team is going to build a model of a comet! Be sure to answer the questions on Page 3 as you proceed.

Team Roles:

Chef – Mix ingredients when the Ingredients Expert tells you to do so. When all of the ingredients have been added, YOU form the comet in your hands.

Ingredients Expert – As you read the directions, retrieve the ingredients and measure the amount needed. Add it to the comet bowl, and the Chef will mix it together.

Recorder – For every ingredient your team adds to the comet, you will record the answers to the questions on this worksheet. There will be questions to answer for every ingredient added, so make sure the rest of the team waits to move on to the next ingredient until the questions have all been answered. Consult with your teammates for the answers.

Materials:

- Measuring cup (at least 1 cup capacity)
- 3 cups of water
- A few drops of sudsing ammonia
- A handful of sand
- A splash of cola
- Large wide mixing bowl
- Large wooden or plastic spoon for stirring
- Heavy dishwashing gloves (2 pairs per group)
- Protective eye goggles (1 per student)
- Newspaper (enough to cover the work area)
- 2.5 cups of dry ice

CAUTION!

The temperature of dry ice is -79˚C (-110˚F). Any more than brief exposure will cause severe "burns." ***Everyone handling dry ice MUST wear heavy rubber gloves!***

Procedures:

1. EVERYONE must wear eye goggles!

2. The **Chef** and **Ingredients Expert** must put on gloves. The **Recorder** will have to write, and therefore does not need to wear the gloves. Just remember not to touch the ingredients unless you are wearing gloves.

3. Cover your desk or table with newspapers.

4. Using the measuring cup, pour 2.5 cups of water into the mixing bowl. Complete the Ingredients Chart on Page 3 for this ingredient.

5. Add a handful of sand. Complete the Ingredients Chart on Page 3 for this ingredient.

6. Add a few drops of ammonia. Complete the Ingredients Chart on Page 3 for this ingredient.

7. Add a splash of cola, mixing as you pour. Complete the Ingredients Chart on Page 3 for this ingredient.

8. Add 2.5 cups of dry ice to the mixture, stirring carefully with a plastic or wooden spoon. Vapor will form as you stir, and the mixture will get slushy. Keep stirring for a few seconds while the mixture thickens. Complete the Ingredients Chart on Page 3 for this ingredient.

9. Use the mixing spoon to clean the slush away from the sides of the bowl into the bottom.

10. **Chef**: Reach in and pack the slush into a ball. Keep packing and forming the slush until you have a ball that forms a big lump.

11. If the mixture is too dry and the mixture is not sticking, add water. If the mixture is too wet and slushy, add more dry ice.

12. Set your comet on the desk (make sure newspapers are underneath) and observe the behavior of your model comet nucleus.

DO NOT HANDLE DRY ICE MIXTURE WITH BARE HANDS!

Ingredients Chart

Questions:

As you add each ingredient, answer the following questions about each and place the answers in the chart:

Column 1: What is the name of the ingredient that you are including in your model comet?

Column 2: What is the corresponding real comet ingredient? In some cases they will be the same as the ingredient you added for the model, and in some cases the model simply represents something else in the comet.

Column 3: Are the ingredients the same in the model and in the actual comet? For the ones that are different, why would we not use the same thing we find in the comet?

Column 4: What is the chemical formula for the ingredient? (Example: Water is H_2O. If there is no chemical formula available, list elements involved.)

Column 5: What is the significance of the ingredient? Is it necessary for life? Does it tell us about conditions in which the comet was formed? Which part of the comet does it represent, and how? Etc.

Model Ingredient	Corresponding Comet Ingredient	Same? If not, why not?	Chemical Formula (or elements involved)	Significance?

Student Worksheet 3:
Famous Comets

Name ____ Date ___________

Your team is going to research a famous comet and report back to the rest of the class.

Procedures:

1. Decide which team member will perform each of the following roles:
Recorder: Records the results of the team's research.
Computer Operator: Uses the computer to navigate the Internet and print out any essential materials.
Literary Supervisor: Records team's input for the story.
Reporter: Presents the team's story to the rest of the class.

2. Name of your team's comet: ____

3. Using the Internet, answer as many of the following questions as possible. Have the recorder write down what the team learns on a separate sheet of paper.

- When was the comet discovered?
- Who discovered the comet?
- What country was the discoverer from?
- Is the discoverer a professional or an amateur astronomer?
- What makes this comet unique or otherwise interesting?
- How long is this comet's orbital period?
- How did you determine the comet's orbital period?
- Have any major events in history happened when the comet has appeared? What were they?
- How did this comet change the way astronomers think about comets or the Solar System in general?
- How did technology change the way we think about comets?
- Print out a picture of the comet. Label its coma, gas tail, dust tail, and nucleus (if visible).

4. Use the following writing prompts to help your team write a two-page story about your comet. Have the *Literary Supervisor* write the story as the rest of the team provides ideas and suggestions. Base your story on actual facts and science concepts.

- Imagine you are a reporter writing a headline story about the sighting of this comet.
- Imagine that you belong to another culture in another century when your comet appears. Describe what you see, what you think it is, and how you feel.
- Imagine you are an amateur astronomer watching the night sky when you think you discover a comet. How do you feel? Who do you tell of your discovery?
- Imagine you are the comet. Talk about where you would travel during your entire orbit.
- Think of your own story!

5. If available, illustrate your story with the photo you printed of your comet. Make sure that the parts of the comet are labeled.

Reflection & Discussion

1. What do comets have in common? How are comets different?

2. Do you think that a comet may hit a planet sometime in the future? Why or why not?

3. Does a comet's tail ever point towards the Sun? Why not?

4. Do you think that we see a lot of the Solar System's comets or only a few? Why can't we see the other ones?

5. If you were alive 1,000 years ago and you saw a comet, how would you feel? Would you be excited? Scared?

6. Do you think we will ever know all there is to know about comets?

7. Did you think that some of the old ideas about comets were strange? Why? Do you think that people will someday think that our ideas about comets are strange? Explain.

8. What effect does the Sun have on comets?

9. What was the most recent visible great comet?

10. What comets will appear in the night sky over the next three years?

11. What robotic spacecraft missions to study comets are currently underway or being planned?

Transfer/Extension

1. Explore how other astronomical objects such as the Sun, Moon, planets, and stars were interpreted by ancient cultures.

2. Research examples of artists' noting comets in paintings, literature, tapestries, and photographs.

3. Invite amateur astronomers into the classroom and ask them to talk about their hobby.