JOURNEY through the UNIVERSE

Voyage: A Journey through our Solar System

Grades 5-8

Lesson 7: Is There Anyone Out There?

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 7: Is There Anyone Out There?

Lesson at a Glance

Lesson Overview

Once scientists have determined where they want to look for life in the Solar System, the next step is to figure out how it is to be done. In this lesson, students first create an operational definition of life, and put it to the test by observing a mystery object. They then define and conduct an experiment, modeled after the life science experiments performed by the Viking Landers on the surface of Mars, to determine if they have discovered life forms in simulated Martian soil samples. The experiment is a simple but dramatic model exploring the differences between chemical and biochemical reactions—which is key to revealing the presence of life.

Lesson Duration

Two 45-minute class periods plus 5 minutes of two class periods for observations

Core Education Standards

National Science Education Standards

Standard C3: Regulation and behavior

All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.

Standard C5: Diversity and adaptations of organisms

Millions of species of animals, plants, and microorganisms are alive today. Although different species might look dissimilar, the unity among organisms becomes apparent from an analysis of internal structures, the similarity of their chemical processes, and the evidence of common ancestry.

AAAS Benchmarks for Science Literacy
Benchmark 5C3:
Within cells, many of the basic functions of organisms—such as extracting energy from food and getting rid of waste—are carried out. The way in which cells function is similar in all living organisms.

Essential Questions

- What defines whether an object is living or non-living?
- How can we search for the presence of life on other worlds?

Concepts

Students will learn the following concepts:

- Defining whether something is living or non-living is not trivial.
- Scientists conduct experiments to determine whether there is life elsewhere in our Solar System.
- Life could exist in many forms, not simply human.

Objectives

Students will be able to do the following:

- Create an operational definition of life based on the observations of their mystery object.
- Conduct an experiment with simulated Martian soil samples.
- Analyze data to determine the absence or presence of life in the soil samples using an operational definition of life.

Science Overview

For as long as people have known (or suspected) planets to be unique worlds and not just specks of light moving around in the night sky, humans have wondered, "Are we alone? Or are there other worlds with living creatures on them? Is Earth the only planet with life thriving on it, or are there other abodes of life out there?" For philosophical reasons alone, an answer to this question is important, because it can provide a better sense of our place in the Universe. If life on Earth is unique, what makes it so special? On the other hand, if there are lots of other life forms in the Universe, what kind of life is it? Is it similar to life on Earth, or very different?

For centuries there were no scientific ways to answer these questions. It is only during the last few decades that our increased understanding of the planets in the Solar System has made it possible to properly investigate whether there are other places in the Solar System where living beings could exist. Since the Solar System is basically Earth's cosmic backyard, it is the logical first place to examine when searching for the presence of life elsewhere in the Universe.

What Is Life?

Before looking for signs of life elsewhere in the Solar System, it is important to determine exactly what to search for. At first, it may seem easy to determine what is life—how to tell whether something is alive or not. For example, a dog running in the park is alive, but a car driving down the street is not. But what proves that one is alive while the other is not?

It is difficult to come up with a good, firm scientific definition of life. There appears to be no single property that distinguishes entities that are alive from those that are not. Instead, there are several characteristics that are shared by most life forms on Earth, such as reproduction or replication; growth; metabolism; gas exchange (respiration); capability to maintain an internal environment separate from its surroundings with the help of a membrane or a wall (cells); organic molecules; movement; and adaptation to the environment. It is good to remember, though, that some non-living entities (such as fire) may have several characteristics from the list, while some organisms that may be living (such as a virus) possess only a few of them.

Some scientists define life as a self-contained chemical system capable of undergoing biological evolution. This provides a long-term view of life—governed by adaptation and evolution—combined with the short-term processes guiding the lives of individual organisms. It is difficult, however, to look for signs of life elsewhere in the Solar System with a long-term definition of life in mind. Instead, a better approach may be to identify environments which are hospitable to life, and then observe whether there are life forms that interact with the environment in a predictable way.

Characteristics of an Environment Hospitable for Life

The first step in assessing whether an environment—either here on Earth or on another planet or a moon—is a candidate for hosting life is to determine whether it meets the basic requirements for life. All life forms on Earth require nutrients, liquid water, a source of energy, protection from harmful radiation, and a stable environment.

Nutrients are the raw materials from which living organisms construct their bodies. Once constructed, additional nutrients are required for maintaining the organism's cellular structure.

Liquid water is important because it dissolves the chemicals that are the basic components of the organisms. In this manner, liquid water gives the chemicals an opportunity to mix together, to react, and to be moved to different parts of the organism.

Energy is needed for a variety of biological activities, such as growing, reproducing, and maintaining the internal organization of living organisms. Most of the energy that life uses on Earth comes from sunlight. Producers are organisms (e.g., plants), which use photosynthesis to store sunlight's energy into food energy. Consumers (e.g., animals) get their energy by eating plants and other organisms. There are organisms on Earth that have adapted to harsh environments—such as bottoms of the oceans or deep underground—where sunlight is not available. Since these environments do not have sunlight to support the first links in the food chains there, organisms use other sources of energy, such as energy from Earth's hot interior. It is possible that on other worlds in the Solar System, energy sources other than sunlight are important, especially if the world is much further away from the Sun than Earth.

Living beings cannot tolerate high levels of harmful radiation coming from the Sun: radiation such as high-energy light like ultraviolet, X-rays, and gamma rays, or high-speed particles flowing out from the Sun as the solar wind. Earth's atmosphere protects organisms here on the surface against these kinds of radiation. On other planets or moons, strong magnetic fields and thick atmospheres can provide adequate protection, or life forms could have developed under some protective cover, such as rocks or ice.

Life forms also need a stable environment, where the environmental conditions do not change rapidly or drastically. For example, the range of temperatures where life forms can be found on Earth spans from about -15°C (5°F) to 113°C (235°F); for a listing of different kinds of extreme environments (including the hottest and coldest environments in which life forms have been found), see the astrobiology web sites listed in the *Internet Resources & References* section. There are no known creatures that could live in an environment in which the temperatures change from one extreme to another. Instead, specific creatures have adapted to a particular stable temperature environment.

Basic Chemistry of Life

The next step in looking for life elsewhere in the Solar System is to find out how to detect signs of life forms interacting with their environment. One possibility is to use the definition of life described above as a "self-contained chemical system," and try and detect how the basic chemistry of life could be interacting with the environment on an alien world.

Organic molecules contain carbon atoms. Carbon atoms can combine in many different ways with other atoms, and millions of different organic molecules have been identified. They are biologically interesting because they are the building blocks of organisms, and they take part in the various chemical processes taking place inside organisms. Organic molecules can also occur in nature without the presence of organisms (for example in interstellar clouds in space); so detecting organic molecules in an environment is not a guarantee that living beings are present. However, it is difficult to imagine organisms being present in an environment in which there are no organic molecules, so their presence (or lack thereof) can serve as a constraint. Some scientists have speculated that alien life forms might be based on some other chemical element than carbon (such as silicon), but it is difficult to beat carbon's versatility in chemical processes. The general thinking on the topic is that any extraterrestrial life forms probably would be made of organic molecules—molecules containing carbon.

The basic chemical processes of life on Earth are photosynthesis and chemosynthesis. In both processes, sugars are produced from water and carbon dioxide with the help of an energy source. The production of sugars converts inorganic carbon from the environment into organic carbon within organisms. Sugars are a way to store energy inside the organisms so that it can be used when needed. In photosynthesis, sunlight is used as the energy source to produce sugars, and oxygen is released as a waste product. Chemosynthesis uses geothermal or chemical energy as the energy source in places where sunlight is not available, such as underground or at the bottom of the oceans. Photo- or chemosynthetic organisms form the basis of all food chains on Earth—further links in the food chains include consumers that get their energy by eating other organisms.

Organisms break down foods into their component parts. The components can then be used as raw materials to build and maintain the organism. They may also be stored in the body of the organism to be used when energy is required. One way to investigate whether there are living organisms in an environment is to supply nutrients (food) into the environment and observe whether metabolic reactions take place—such as growth of living organisms in the environment, or heat is generated when energy is used to power biological activities.

Respiration is an important metabolic process. It is the process in which the cells of an organism break down foods and release energy to power life processes. Respiration can be viewed as the reverse of photosynthesis: the energy stored in food is released with the help of oxygen, and carbon dioxide is released as a by-product. In anaerobic respiration molecules such as carbon dioxide, nitrate, nitrous oxide, or sulphur are used instead of oxygen to help release the energy stored in food. Single-celled organisms can take the gases needed for respiration directly from and release the waste products directly to their environment. In multi-cellular organisms (such as humans), specific organs (lungs) have developed to aid in the process. In all cases, the characteristic process is an exchange of gases; a living organism takes a gas (e.g., oxygen) from the environment to power life processes, and releases other gases (e.g., carbon dioxide) as a by-product.

Looking for Life in the Solar System

Knowledge of the characteristic environments in which life is expected to be discovered, and of the basic ways in which living organisms are expected to interact with their environment, can be used as a starting point to investigate whether life forms could exist elsewhere in the Solar System. The branch of science interested in these kinds of questions is astrobiology. It is, in essence, the study of the origin of life on Earth and the possibility of life elsewhere in the Universe.

The most likely type of life that astrobiologists expect to find in the Solar System is microbes. Microbes are extremely small organisms that on Earth live in a wide variety of places—even environments that are inhospitable to other life forms. Because of the large range of conditions in which microbes can thrive, they are the most likely kind of life to be found anywhere where conditions might be suitable for life, and in many places where no other kind of life could survive. Discovering even just microbial life outside of Earth would be significant, because it would suggest that as long as conditions are right for life forms to survive, life can develop.

Mars is one of the best candidates for hosting life beyond Earth. Though smaller than Earth, Mars is similar in many other ways, most importantly for having had abundant water on its surface at least at some point in its history. Mars is known to have had water in the form of rivers and seas on its surface in the past, and even today, there is water vapor in the atmosphere, permafrost on the surface, and water ice underground. It is at these places—where there is or was water—that life, or evidence of past life, may exist. It is not surprising that one of the first—and so far only—significant efforts to find signs of life in the Solar System using robotic spacecraft was done on Mars.

Viking Missions to Mars

In the 1970s, NASA conducted the Viking mission to study Mars. Viking 1 and Viking 2 were twin spacecraft, each consisting of an orbiter, which studied Mars from an orbit around the planet, and a lander, which landed on the surface of the planet. Viking 1 was launched on August 20, 1975, and arrived at Mars on June 19, 1976. Viking 2 was launched on September 9, 1975, and arrived at Mars on August 7, 1976. The orbiters took pictures of the Martian surface, and based on the analysis of these images, two landing sites were selected. Viking 1 lander touched down at Chryse Planitia on July 20, 1976, and Viking 2 landed at Utopia Planitia on September 3, 1976. Both landing sites were fairly flat, featureless plains, chosen because they appeared to be the best bets for a successful landing. The Viking spacecraft continued scientific investigation of Mars for several years; Viking 1 orbiter was powered down on August 17, 1980, and Viking 2 orbiter on July 25, 1978. Contact with the Viking 1 Lander was lost on November 13, 1982, due to an erroneous command sent by ground control on Earth. Viking 2 Lander continued communications until April 11, 1980, when its batteries failed.

The main goals of the Viking spacecraft were to take pictures of the Martian surface, examine the nature of the Martian atmosphere, and search for evidence of life. The orbiters observed the planet closely throughout their operation. They took thousands of pictures of the surface of the whole planet at a resolution of 150-300 m (490-980 ft)—that

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is, details of this scale could be seen on the Martian surface. Some parts of the surface were pictured at an even higher resolution—details as small as 8 m (26 ft) in size could be seen in these pictures.

The Viking landers took over 1,400 pictures of the surface around the landing sites. They analyzed samples of the surface to examine its properties. They studied the composition of the atmosphere and observed Martian weather. They used seismometers to determine whether Mars has marsquakes (the Martian version of earthquakes); Viking 1 lander's seismometer turned out not to be operational, and Viking 2 lander did detect any quakes. At each landing site, the landers also conducted comprehensive biology experiments to investigate several phenomena in the environment to determine whether there were any signs of life there.

Using Cameras to Search for Signs of Life

Each Viking lander had two cameras that viewed the scenery surrounding the lander. In addition to providing basic information on the environment and geologic features, the pictures taken by the cameras could have shown visible signs of biological activity near the landers (such as movement). None was detected.

Searching for Organic Molecules on Mars

The Viking landers included an arm designed to collect samples of the Martian surface for analysis. A basic chemical analysis of the samples looked for the presence of organic molecules. While there are carbon-containing compounds on the Martian soil and in the atmosphere—after all, carbon dioxide is the main component in the Martian atmosphere—no real organic molecules were detected, not even those expected to be there from meteorite impacts over the history of the planet. The currently favored explanation for the lack of organic molecules is that Martian soil contains chemicals that can destroy organic molecules.

Searching for Signs of Metabolic Processes on Mars

Three experiments aboard the landers were designed to investigate whether any photosynthetic or metabolic activity could be detected. In each case, the experiments placed Martian soil samples in different environmental conditions and observed them over a period of time. In some cases, samples were heated and sterilized for comparison.

The Pyrolytic Release experiment was designed to detect photosynthetic activity in any organisms contained in the soil samples. In the experiment, soil samples were mixed with carbon dioxide and carbon monoxide. If there were organisms in the soil capable of photosynthesis, they would convert the inorganic carbon into organic carbon. These organic compounds would then be contained in the soil after the experiment. The initial experiment showed that some of the carbon was, indeed, incorporated into the soil. However, when the samples where heated to a high temperature (650ºC; 1200ºF) to kill off any organisms in the sample, and the experiment repeated, carbon was still being incorporated into the soil. This suggested that something else was converting carbon from gas into the soil, and biological activity may not have been the reason.

The Labeled Release experiment attempted to find signs of metabolism and respiration from organisms in the soil samples. In the experiment, liquid nutrients (a "soup" of material thought to promote biological activity) tagged with radioactive trace gases were added to the soil samples. The atmosphere above the samples was carefully monitored to see if any gases were released as a result of respiration by organisms consuming the nutrients. The results indicated that a significant amount of gases were released after feeding the nutrients to the samples. After heating the samples to a high temperature to kill off possible biological entities, the experiment was repeated. The amount of gases released in the experiment after the heating was reduced, just as would happen with soil samples containing micro-organisms on Earth. The labeled release experiment seemed to suggest biological activity might be present in the soil samples.

The Gas Exchange experiment investigated whether respiration was occurring in the samples. In the experiment, a soil sample was placed in a monitored atmosphere. Nutrient solution was fed to the sample, and the atmosphere above the sample was carefully monitored. As soon as the nutrients were introduced, significant gas exchange was observed. However, when the sample was heated to a high temperature to kill off organisms, gas exchange still continued. Also, even if the sample was given just water, and not nutrients, gas exchange was observed. This suggested that some other process besides biological activity was responsible for the observed results.

Results of the Viking Biology Experiments

The results from the biological experiments aboard the Viking landers were mixed. Before the mission, scientists had established criteria to decide if life would be detected in the samples. The experiments actually met the criteria, but, unfortunately, some of the results indicated that biological activity may not be the best explanation for the observed results. The lack of organic molecules was one of the critical problems.

Later, the Viking lander biological experiments were reproduced in laboratories on Earth using just inorganic chemistry. This led scientists to announce that no evidence of life on Mars was discovered in the experiments. However, there are still scientists who suggest that since the experiments gave results which suggested the possible presence of biological activity, life could have been present in the samples. It is also possible that the Viking landers touched down on areas particularly harsh on living organisms—after all, the landing sites were chosen based on the ease of landing rather than the likelihood of finding life.

Other Investigations for Signs of Life on Mars

To address the unsolved question of the possibility of life on Mars, further studies have been conducted since the Viking missions. One recent investigation was centered on the Martian meteorite, ALH84001. Several meteorites are known to have come from Mars, based on atmospheric gases trapped in pockets within the rock. The meteorite, found in Antarctica, dates back to an early period on Mars when the conditions were much wetter and more suitable for life. Formations in the rock suggest that it may contain a fossilized form of bacteria, although the proper interpretation of the rock's features has remained a subject of vigorous debate and inquiry among many scientists. The current opinion on ALH84001 by the majority of scientists is that the evidence for a fossilized life form in the meteorite is not strong enough to proclaim the presence of ancient life on Mars. As with the Viking biology experiments, more data is needed.

Clearly, determining whether Mars has life on it now, or whether Mars may have had life in the past, remains an interesting issue of study. Several spacecraft have headed to Mars in recent times, and several more missions are planned over the next few years, to help determine whether Mars really has conditions suitable for life, or had them sometime in the past, and whether any living organisms exist(ed) at those times. In the meanwhile, the consideration of possible habitats of life on other worlds in the Solar System is extending beyond Mars. However, Mars remains the likeliest place in the Solar System where extraterrestrial life could be discovered one day.

Conducting the Lesson

Warm-Up & Pre-Assessment

Teacher Materials

- Blackboard or whiteboard
- Optional: a wrist watch

Preparation & Procedures

1. Present the following question to your students: If you left a wristwatch on Mars, and a Martian happened to find it, how would (s)he determine if it was living or non-living?

2. Discuss with students what characteristics the Martian would look for and create a list on the board. Students should generate suggestions such as movement, growth, reproduction, etc.

3. Use student answers to discuss reasons why the Martian may be confused about whether or not the watch is alive. For example, parts of the watch move (hands) and it makes noise, just like a bear, therefore is it alive? A car and a remote controlled toy do the same, so are they alive? Defining what is alive is more difficult than it initially appears.

NOTES:

Activity 1: Is It Alive?

Students will be given mystery objects that they tend for several days. Students will observe their objects, note any changes, and conclude whether or not the objects are alive. Students then use these observations to refine their original list of characteristics possessed by life.

Student Materials

Per Student:

- 2 copies of Student Worksheet 1

Per Group:

- Student Care Sheet

Per Group with Object A:

- 1 cup of baking soda
- 1 cup (~240 ml) of vinegar
- 1 disposable clear plastic cup
- 1/3 cup measuring cup or graduated cylinder

Per Group with Object B:

- 1 set of brine shrimp eggs
- 1 teaspoon (5 grams) of salt
- Teaspoon or scale to measure grams
- Resealable clear water bottle
- Distilled water (enough to fill water bottle)

Per Group with Object C:

- 4 bean seeds (e.g., fava beans, kidney beans, black-eyed peas)
- 1 paper towel
- Resealable plastic bag
- Distilled water (enough to wet paper towel)

Per Group with Object D:

- 4 small pebbles that resemble seeds
- 1 paper towel
- Resealable plastic bag
- Distilled water (enough to wet paper towel)

Per Group with Object E:

- 1/2 cup (120 ml) of a saturated soluble sugar solution (See Teacher Care Sheet for details—about 1 cup of water, 2 cups of sugar, and a hot plate are needed)
- 1 paper clip
- 12 inches (30 cm) of string
- 1 washer or bolt

Student Materials (Continued)

Per Group with Object F:

- 1 sprig of elodea
- 1 teaspoon (5 ml or) of bromthymol blue
- Resealable clear water bottle
- Graduated cylinder or teaspoon
- 1 straw

Per Class:

- Optional: Magnifier

Preparation & Procedures

1. Hand out two copies of Student Worksheet 1 to each student. Read the introduction aloud as a class.

2. Ask students to complete step 1, which is to brainstorm a list of characteristics that all living things share. They may use the suggestions on the board from the *Warm-Up & Pre-Assessment* or generate ideas of their own.

3. Divide students into cooperative groups of three students. Give each group two mystery objects—one living and one non-living (see the table on the next page for the list of living and non-living objects.) Also give each group of students a copy of the Student Care Sheet, located in the back of the lesson. Ask students to read the care sheets carefully. They must ensure the safety of their mystery object.

4. Have students set up the habitat needed by their mystery objects, as outlined on the Student Care Sheet, and make their first observations. They should record their observation on the data table in Student Worksheet 1 (students should have two copies of Student Worksheet 1, one for each object).

5. Have students care for and observe their objects over the next two days as described on their Care Sheet.

6. Have students answer questions 3 and 4 on Student Worksheet 1 based on their observations over the three days.

7. Have students prepare a short presentation to the class on their mystery objects, including their observations and determination of whether the objects are living or non-living.

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Reflection & Discussion

As each group of students presents, make sure they address the points in the chart below. You may need to ask guided questions; see the chart for suggestions. After the students' presentations, tell the class what their mystery objects really are.

Show students the original list of the characteristics for life that they generated during the *Warm-Up & Pre-Assessment*. Based on their observations, ask students if they should add or remove any criteria from their original list. Have students support their answers with examples from their observations and observations of their peers.

Mystery Object	Living or Non-Living?	Teacher Prompt	Desired Student Answer
A – Baking Soda	Non-Living	Why does the reaction start strong and reduce with each additional "feeding"?	It was a chemical reaction that stopped when all of the reactants ran out; it was not a biological process.
B – Brine Shrimp	Living	Why didn't you see movement right away?	The brine shrimp eggs needed time to hatch.
C – Bean Seeds	Living	What observation lead you to the conclusion that your object was alive?	The seed germinated, and a stem and leaves grew.
D – Pebbles	Non-Living	Can you make any reasonable arguments that your object may be alive?	◗ Perhaps the environment we established for the object is not conducive for it to live. ◗ Perhaps the object needs more time to flourish, like a butterfly in a cocoon.
E – Sugar Solution	Non-Living	Your object was able to grow; why is it not alive?	The object did display one characteristic we indicated in the *Warm-up & Pre-assessment*. However, there is no one characteristic that tells us if something is alive, but it is the combination of all of them.
F – Elodea	Living	Why does the color of the bromthymol blue continue to change color?	Because the object (plant) is absorbing the carbon dioxide for photosynthesis. This reaction does not stop because it is a biological reaction, not a chemical reaction.

Transfer of Knowledge

Based on this activity, have the students, or groups of students, come up with a definition of life in the *Transfer of Knowledge* section in Student Worksheet 1. Their definitions might include some of the following:

- Continued metabolic processes that show chemical exchanges that may be detected in some sort of respiration. For example, animals take in carbon-based organic molecules and oxygen, and expel carbon dioxide.
- Exchange of gases or solid materials.
- Reproduction, replication, or cell division.
- Continued reaction to stimuli.

Assessment Criteria for Activity 1

5 Points

- Student Worksheet 1 is complete and accurate.
- *Transfer of Knowledge* is complete and accurate.

4 Points

- Student Worksheet 1 is complete and mostly accurate.
- *Transfer of Knowledge* is complete and mostly accurate.

3 Points

- Student Worksheet 1 is complete and somewhat accurate.
- *Transfer of Knowledge* is complete and somewhat accurate.

2 Points

- Student Worksheet 1 is mostly complete and somewhat accurate.
- *Transfer of Knowledge* is mostly complete and somewhat accurate.

1 Point

- Student Worksheet 1 is somewhat complete and accurate.
- *Transfer of Knowledge* is somewhat complete and accurate.

0 Points

- No work completed.

Extensions

- Have students view each object under a magnifier to see if they can detect the presence of cells, another characteristic of life.
- Increase the number of mystery objects used by the students. For example, use snails, vermiculite, or fungi.

Placing the Activity Within the Lesson

Now that students know how to identify life, ask them for ideas about how they can begin to look for the signs of life on other worlds.

Notes on Activity 1:

Activity 2: Searching for Signs of Life

Students will perform experiments on simulated Martian soil samples to try and determine if life is present. Students "feed" the samples and observe them for signs of any reaction. The nature of the observed reaction is then used to discern if it is a telltale sign of life. This activity is modeled after the life science experiments conducted by the Viking 1 and 2 Landers on the surface of Mars in the mid- to late 1970s.

Student Materials

Per student:

- Goggles
- Student Worksheet 2

Per group of 3 students:

- 3 clear small plastic cups (6 oz plastic wine tumblers work well)
- Large plastic cup (about 20 oz capacity)
- 3 tablespoons (45 g) of sugar
- Tablespoon or scale to measure grams
- Magnifying glass
- Sand or sandy soil (enough to fill the three small cups 1/4 full)
- Half a packet of instant active dried yeast
- 1 Alka-Seltzer® tablet crushed into powder
- Pot of water (about 2 cups)
- Hot plate, Bunsern burner, or similar, to heat the pot of water
- Thermometer that measures at least up to 50°C
- Paper plate

Preparation & Procedures

1. Before class, prepare the soil samples: Label a set of three small plastic cups for each group "A," "B," and "C." Fill all cups 1/4 full of sand. Mix half a packet of instant active dry yeast into the sand in each cup labeled "B." Stir. For each cup labeled "C," crush a tablet of Alka-Seltzer® into a fine powder and mix it into the sand. Stir.

2. Heat a pot of water on a hot plate or over a Bunsen burner and heat until the water is 40-50°C. If the water is too cold the yeast will not react; if the water is too hot the yeast will be killed.

Teaching Tip

Make sure that the students cannot see any signs of what the soil samples contain. Dispose of yeast and Alka-Seltzer® packages in a place where the students cannot read the containers. They should not know what is in each sample before the experiment.

3. Ask students, "Based on your research in Activity 1, if you were going to look for life on Mars, what is the first thing you would look for?" (*Desired answer: movement*) Tell students that when the Viking Landers reached Mars in 1976, that's exactly what they did. They were equipped with cameras that looked for movement. However, no movement was detected. Ask students if living beings that walk around on the surface are the only kinds of life possible? (*Desired answer: no, there could be microscopic life living in the dirt on Mars.*)

4. Divide students into the same groups as in during Activity 1. Have each group take a set of cups A, B, and C. Explain to the students that each team has a set of simulated Martian soil samples, which are physical models of the real Martian soil that were analyzed by the Mars Viking Landers in the 1970s. Their assignment is to make careful observations and check for indications of living material in the soils based on the criteria they established in Activity 1. Have students complete Part I of Student Worksheet 2.

CAUTION: Students must observe all safety procedures, including personal safety and safe handling of materials.

5. Ask students how they could detect life in these samples. (*Desired answer: Look for gas exchange, or evidence for breathing and/or giving off waste.*) What will life take in? (*Desired answer: food*) Ask students what they should feed it. (*Desired answer: sugar*) Sugar is a common nutrient for many living beings, and all life as we know it needs water, so sugar water (which we could call "chicken soup" since it's good for everyone!) is a good choice. Have students prepare the sugar solution by pouring 1-2 cups of warm water into a large plastic cup and mixing in 1 Tbsp (15 g) of sugar for every cup of water included. Instruct students to follow the directions for Part II on Student Worksheet 2, but not to move on to Part III.

6. After the students have recorded their observations of the first "feeding," discuss what happened. (There should have been reactions in cups B and C, but not in cup A.) Are they convinced that there is something alive in cups B and C? (*Desired answer: No, it could be a chemical reaction, as seen with some of the mystery objects in Activity 1*) How could we determine if there is a chemical reaction, or if there is something alive? (*Desired answer: feed it again. If there is still a reaction, then it might be alive. If there is not, then all of the chemicals could have been used up.*)

7. Have students complete Part III of Student Worksheet 2.

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Assessment Criteria for Activity 2

5 Points
- *Transfer of Knowledge* is complete and accurate.
- All observations on Student Worksheet 2 are complete.
- Observations accurately describe the results.
- Writing is clear and understandable.

4 Points
- *Transfer of Knowledge* is complete and mostly accurate
- All observations on Student Worksheet 2 are complete.
- Observations describe the results.
- Writing is clear and understandable.

3 Points
- *Transfer of Knowledge* is complete and somewhat accurate.
- Observations on Student Worksheet 2 are mostly complete.
- Observations describe the results.
- Writing is understandable.

2 Points
- *Transfer of Knowledge* is mostly complete and somewhat accurate.
- Observations on Student Worksheet 2 are few, but acceptable.
- Observations attempt to describe the result.
- Writing is difficult to understand.

1 Point
- *Transfer of Knowledge* is somewhat complete and accurate.
- Observations on Student Worksheet 2 are not complete.
- Observations do not describe the results.

0 Points
- No work completed.

Reflection & Discussion

1. Ask students how the second "feeding" differed from the first "feeding." (*Desired answer: cup B should have continued to react, but cup C stopped reacting.*) Which cup do you think is more likely to contain life? (*Desired answer: cup B*) Do we know for sure that cup B contains life? (*Desired answer: no*) How could we be more confident that cup B contains life? (*Desired answer: we could keep feeding it. If it is chemical, then eventually the reactant will be used up and it will stop reacting. We could also conduct different types of experiments, such as examining it under the microscope to look for cells.*)

2. Is it possible that cups A and C also contained life, but our experiment could not detect it? (*Desired answer: yes, perhaps the life forms in the cups did not like the sugar solution we fed them (our "chicken soup"), so they did not eat it. Perhaps the solution was poisonous to those life forms. Perhaps we drowned the life with too much sugar solution. Or perhaps the biological reaction stopped because the organisms died in the waste they produced.*)

3. After the class discussion, tell the students that sample A contained only sand, sample B contained sand and some added yeast, and sample C contained sand and some added Alka-Seltzer®. Ask students to reexamine their answer to Question E in Student Worksheet 2 in light of this new information.

Transfer of Knowledge

Have students write an essay explaining how the criteria for life they identified in Activity 1 was reflected in their experiment in Activity 2, and how they would improve this experiment to reflect those characteristics that were not tested.

Extensions

Research missions to Mars, such as the Mars Viking Landers, or Spirit and Opportunity rovers, and how they searched for signs of life and hospitable environments for life.

Placing the Activity Within the Lesson

Students had to apply what they learned about identifying life in Activity 1, in order to determine the absence or presence of life in Activity 2. Point out that this is how scientists work, too. They establish criteria on how to look for life based on what they observe here on Earth, and then design experiments to be done on alien worlds. Students had to be careful to distinguish between chemical reactions and biological reactions in order to draw conclusions about the soil samples.

Notes on Activity 2:

Lesson Wrap-Up

Transfer of Knowledge for the Lesson

Have students read the Student Information Sheet: Viking Missions to Mars, which describes the experiments carried out by the Mars Viking Landers in search for signs of life. Instruct students to create a poster, using images in addition to words, summarizing all of the experiments and their results.

Assessment Criteria for the Lesson

5 Points
- Student summarized each Viking Lander biological experiment.
- Student summarized the findings of each experiment.
- Student summaries were accurate and in their own words.
- Student's poster contained images in addition to words.
- Student's poster was neat and well organized.

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

Discuss with the students how else they would look for life on Mars or elsewhere. Have them refer to their conclusion from Activity 1 and discuss what other types of experiments they could design.

Extensions for the Lesson

See the *Science Overview* for information about the Mars meteorite ALH84001. Place students into teams to debate whether the suggestion of fossilized life in the meteorite is convincing based on the scientific evidence.

Resources

Internet Resources & References

Student-Friendly Web Sites:

AstroVenture
astroventure.arc.nasa.gov/
Habitable Worlds
nai.arc.nasa.gov/astrotech/solarindex.cfm
Mars for Kids
athena.cornell.edu/kids/
Welcome to Mars
marsprogram.jpl.nasa.gov/funzone_flash.html

Teacher-Oriented Web Sites:

AAAS Benchmarks for Science Literacy
www.project2061.org/tools/benchol/bolintro.htm
NASA Astrobiology
astrobiology.arc.nasa.gov/
NASA Mars Exploration Program
marsprogram.jpl.nasa.gov/
NASA Viking Mission to Mars
www.nasa.gov/mission_pages/viking/
National Science Education Standards
www.nap.edu/html/nses/
Voyage: A Journey through Our Solar System
www.voyagesolarsystem.org
Journey through the Universe
www.journeythroughtheuniverse.org

Teacher Answer Key

Student Worksheet 1

1. Answers will vary; accept all logical answers. See the *Science Overview* for examples of possible answers.

2. See the Teacher Care Sheet for expected observations.

3. In addition to drawing the correct conclusion, students must support their answers based on their observations. The conclusions should be the following:

Mystery Object	Living or Non-Living?
Object A – Baking Soda	Non-Living
Object B – Brine Shrimp	Living
Object C – Bean Seeds	Living
Object D – Pebbles	Non-Living
Object E – Saturated Sugar	Non-Living
Object F – Elodea	Living

4. Answers will vary. Accept all logical and supported answers.

6. Student definitions might include some of the following:
- Continued metabolic processes that show chemical exchanges may be detected in some sort of respiration. For example, animals take in carbon-based organic molecules and expel carbon dioxide.
- Exchange of gases or solid materials.
- Reproduction, replication, or cell division.
- Continued reaction to stimuli.

Student Worksheet 2

a) There are smooth granules in cup B, and white specks in cup C. If the sand is fine-grained, it will be hard to detect the smooth granules in cup B.

b) B and C.

c) There may be life in all or none. But we know something interesting seems to be happening in B and C. These reactions may be signs of life. But students should recognize that both metabolic and chemical reactions could account for the observed activity.

d) The reaction is seen a second time in cup B, but not in cup C or A.

e) Cup A (plain sand) showed no reaction after the second feeding; it had no biological or chemical reactants. Cup C (Alka-Seltzer®) had a chemical consumable that reacted to the first feeding and was used up in the reaction. Therefore no reaction was observed after the second feeding. Cup B (yeast) contained a biological agent that enjoyed the first feeding, and also continued to enjoy the second feeding. The biological agent is not a consumable and therefore continues to react to consecutive feedings.

f) Continued metabolic reactions.

Teacher Care Sheet

Object A – Baking Soda (Non-Living)

Teacher Instructions: Give the students a plastic cup with a thin layer (2-4 cm; 1-2 inches) of baking soda on the bottom.

Student Instructions: Feed your mystery object 80 ml or 1/3 cup of vinegar every day. Keep your object at room temperature and observe daily.

Expected Reaction: The first day students should see a chemical reaction that produces a lot of bubbles and fizz. The second day they feed their mystery object, the students should see a much smaller reaction, and on the third day they should see no reaction.

Object B – Brine Shrimp Eggs (Living)

Teacher Instructions: Give the students a sample of the brine shrimp eggs in a small plastic cup. Brine shrimp eggs can be purchased at your local pet store; they are commonly used to feed fish. The brine shrimp should hatch within 12 hours and do not need to be fed for four days. On the fourth day they can be fed fish flakes.

Student Instructions: Fill a clear plastic water bottle with distilled water and 1 tsp or 5 g of salt. Add your mystery object and seal tightly. Keep your object at room temperature and observe daily.

Expected Reaction: The brine shrimp eggs will hatch and very small organisms can be seen swimming through the container.

Object C – Bean Seeds (Living)

Teacher Instructions: Give the students four bean seeds. Any type of soup beans will do (e.g. fava beans, kidney beans, or black-eyed peas).

Student Instructions: Wet a paper towel and fold it in half. Place your object on the paper towel and fold the paper towel in half again. Place the moist paper towel containing the object in a resealable plastic bag. Keep your object at room temperature and observe daily.

Expected Reaction: Beans will germinate and sprout a stem and one or two small leaves, or cotyledons.

Object D – Small Pebbles (Non-Living)

Teacher Instructions: Give the students four small pebbles that resemble seeds.

Student Instructions: Wet a paper towel and fold it in half. Place your object on the paper towel and fold it in half again. Place the moist paper towel containing the object in a resealable plastic bag. Keep your object at room temperature and observe daily.

Expected Reaction: No reaction will occur.

Object E – Saturated Sugar Solution (Non-Living)

Teacher Instructions: Prepare a saturated sugar solution by heating a small amount of water (e.g. 100 ml) and continuing to add sugar until it is saturated. Saturation will be reached when sugar starts to accumulate on the bottom of your pan. Give the students a small plastic cup filled with 1/2 cup (~120 ml) of the cooled saturated sugar solution.

Student Instructions: Open a paper clip and tie a string to it. Tie a washer or bolt to the other end. Wet the string and roll it in sugar. Lay the opened paper clip over the mouth of the cup and drop the string into your mystery object. The bolt or washer should weigh your string down. Keep your object at room temperature and observe daily.

Expected Reaction: Crystals will grow on the string.

Object F – Elodea (Living)

Teacher Instructions: Give student, or groups of students, a sprig of Elodea. Elodea is a common aquarium plant and can be obtained at any pet store. Elodea is also a common pond plant and can be harvested from a local pond.

Student Instruction: Fill a clear plastic bottle with distilled water and 5 ml or 1tsp of bromthymol blue. Bromthymol blue is a blue-colored liquid indicator that turns yellow in the presence of carbon dioxide. Using a straw, gently blow into the solution until it turns yellow. Once yellow, the solution will turn back to blue if the carbon dioxide is removed. Add your mystery object to the bottle and seal tightly. Keep your object at room temperature and observe daily.

Expected Reaction: Elodea are plants and will absorb the carbon dioxide from the water solution for photosynthesis. By removing the carbon dioxide, the solution will turn from yellow back to blue.

Object A: Feed your mystery object 80 ml or 1/3 cup of vinegar every day. Keep your object at room temperature and observe daily.

Object B: Fill a clear plastic water bottle with distilled water and 1 tsp or 5 g of salt. Add your mystery object and seal tightly. Keep your object at room temperature and observe daily.

Object C: Wet a paper towel and fold it in half. Place your object on the paper towel and fold it in half again. Place the moist paper towel containing the object in a resealable plastic bag. Keep your object at room temperature and observe daily.

Object D: Wet a paper towel and fold it in half. Place your object on the paper towel and fold the paper towel in half again. Place the moist paper towel containing the object in a resealable plastic bag. Keep your object at room temperature and observe daily.

Object E: Open a paper clip and tie a string to it. Tie a washer or bolt to the other end. Wet the string and roll it in sugar. Lay the opened paper clip over the mouth of the cup and drop the string into your mystery object. The bolt or washer should weigh your string down. Keep your object at room temperature and observe daily.

Object F: Fill a clear plastic bottle with distilled water and 5 ml or 1 tsp of bromthymol blue. Bromthymol blue is a blue-colored liquid indicator that turns yellow in the presence of carbon dioxide. Using a straw, gently blow into the solution until it turns yellow. Once yellow, the solution will turn back to blue if the carbon dioxide is removed. Add your mystery object to the bottle and seal tightly. Keep your object at room temperature and observe daily.

JOURNEY through the UNIVERSE

Student Worksheet 1: Is It Alive?

Name ______________________________ Date __________

In this project, you will be given a mystery object along with a care sheet. Your goal is to take care of your mystery object, make daily observations of it, and determine if it is alive. This may be more difficult than it seems; not all living things behave in the same way.

Procedures:

1. Brainstorm a list of characteristics that all living things share. Keep in mind the variety of organisms that exist in your community as well as around the world.

2. Your Mystery Object (circle one) A B C D E F

   For three days, make daily observations of your mystery object and record your information in Data Table 1.

Data Table 1

Day	Observations
Day 1	
Day 2	
Day 3	

3. Based on the observations you have made, is your mystery object alive? Explain.

4. Refer back to the list you brainstormed in Step 1 on page one of this worksheet. Would you eliminate and/or add any characteristics of living things? Explain.

5. Share your results with the class.

6. **Transfer of Knowledge:** Use your observations and class discussion to create a list of properties that can be used to define life.

Student Worksheet 2: Searching for Signs of Life

Name ______________________________ Date ____________

Your Mystery Objects in Activity 1 (circle two) A B C D E F

You are provided with three different models of Martian soil, which may or may not contain living material. The purpose of this activity is to make careful observations and check for signs of living material in the soils using the definition for life you created in Activity 1.

Directions:

PART I

1. Smell and touch the samples, but DO NOT TASTE them. Record your observations in the Data Log below.
2. Put a few grains from each sample on a paper plate and observe them with a magnifying glass. Record your observations.

PART II

3. Prepare a batch of warm sugar water by pouring 1-2 cups of warm water into a large cup and mixing in 15 g (1 Tbsp) of sugar for every cup of water poured in. Sugar is a nutrient for many living organisms.
4. Add the nutrient solution to each soil sample by pouring only enough to just cover the sample. After this first "feeding," look for any immediate differences caused by adding the nutrient solution. Record your observations in the Data Log.
5. After 10 minutes, again record your observations of the soil samples.

PART III

6. After another 10 minutes, add the nutrient solution to each soil sample again by pouring on only enough to just cover the sample. Observe carefully and record the reaction to the second "feeding."
7. When you are finished with your observations, complete the Questions & Conclusions section.

Data Log

	Sample A	Sample B	Sample C
Smell and touch observation			
Initial visual observation			
First feeding			
After 10 minutes			
Second feeding (after 20 minutes)			

Questions & Conclusions

a) Prior to adding water, what differences did you see in the soil samples?

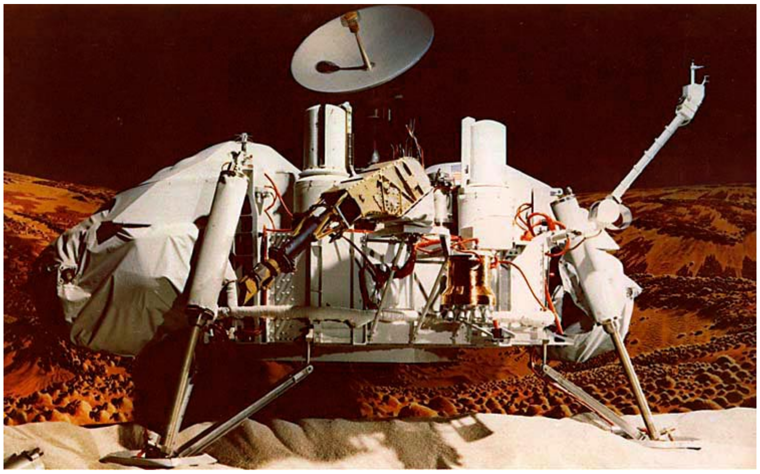
b) Which samples showed activity after the first “feeding”?

c) Does the experiment results indicate that there is life in both B and C, and no life in A? Why or why not?

d) Which samples showed activity after the second “feeding”?

e) How would you explain the difference you observed between the first and second “feeding”?

f) What characteristics of life that you identified in step one are reflected in this experiment?



In the 1970s, NASA sent two spacecraft to study Mars closeup. Viking 1 and Viking 2 were twin spacecraft, each consisting of an orbiter, which studied Mars from an orbit around the planet, and a lander, which landed on the surface of the planet and searched for evidence of life.

The Viking landers took over 1,400 pictures of the surface around the landing sites. They studied the composition of the atmosphere and observed Martian weather. They looked for signs of marsquakes (the Martian version of earthquakes), but did not detect any.

Searching for Signs of Life on Mars

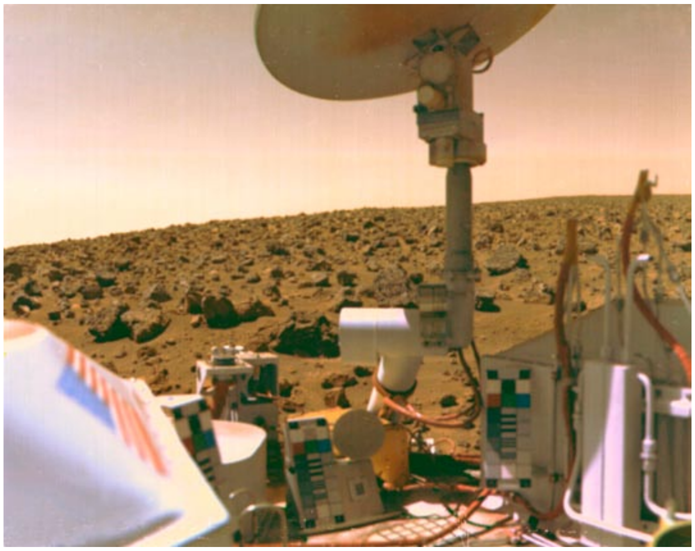
At each landing site, the landers also made a comprehensive examination of the environment to determine whether there were any signs of life there. The first step in determining if any life was present nearby was to analyze the pictures taken by the landers carefully to determine whether there were any visible signs of life nearby (such as movement). None was detected.

The landers analyzed soil samples from the surface to examine its properties and look for organic molecules, which are carbon-containing molecules that are the building blocks of organisms and take part in various chemical processes inside organisms. Organic molecules can also occur in nature without the presence of organisms (for example in interstellar clouds in space); so detecting organic molecules in an environment is not a guarantee that living beings are present. However, it is difficult to imagine organisms being present in an environment in which there are no organic molecules, so their presence (or lack thereof) can serve as a constraint. While carbon-containing compounds were detected on the Martian soil and in the atmosphere—after all, carbon dioxide is the main component in the Martian atmosphere—no real organic molecules were detected.

Searching for Signs of Metabolic Processes on Mars

Three experiments aboard the landers were designed to investigate whether any photosynthetic or metabolic activity could be detected. In each case, the experiments placed Martian soil samples in different environmental conditions and observed them over a period of time. In some cases, samples were heated and sterilized for comparison.

The Pyrolytic Release or Carbon Assimilation experiment was designed to detect photosynthesis in any living organisms contained in the soil samples. In the experiment, soil samples were mixed with carbon dioxide and carbon monoxide to see whether any of the inorganic carbon would be converted into organic carbon by living organisms, in which case the converted carbon would be contained in the soil after the experiment. The initial experiment showed that some of the carbon was, indeed, incorporated into the soil. However, when the samples



A view of the surface of Mars taken by the Viking 2 Lander in 1977. The plain visible beyond the spacecraft is covered with red rocks and dust but has no signs of present or past life. (Picture credit: NASA/JPL/Planetary Photojournal.)

were heated to a high temperature (650ºC; 1200ºF) to kill off any living organisms in the sample, and the experiment was repeated, carbon was still being incorporated into the soil. This suggested that something else was converting carbon from gas into the soil, and biological activity may not have been the reason.

The Labeled Release experiment attempted to find signs of metabolism and respiration from living organisms in soil samples. In the experiment, liquid nutrients (a "soup" of material thought to promote biological activity) tagged with radioactive trace gases were added to the soil samples. The atmosphere above the samples was carefully monitored to see if any gases were released as a result of respiration by living organisms consuming the nutrients. The results indicated that a significant amount of gases were released after feeding the nutrients to the samples. After heating the samples to a high temperature to kill off possible biological organisms, the experiment was repeated. The amount of gases released in the experiment after the heating was reduced, just as would happen with soil samples containing micro-organisms here on Earth. The labeled release experiment seemed to suggest biological activity might be present in the soil samples.

The Gas Exchange experiment investigated whether respiration was occurring in the samples. In the experiment, a soil sample was placed in a monitored atmosphere. Nutrient solution was fed to the sample, and the atmosphere above the sample was carefully monitored. As soon as the nutrients were introduced, significant gas exchange was observed. However, even after the sample was heated to a high temperature to kill off organisms, gas exchange still continued. Also, even if the sample was given just water, and not nutrients, gas exchange was observed. This suggested that some other process besides biological activity was responsible for the observed results.

Results of the Biology Experiments of the Viking Landers

The results from the biological experiments aboard the Viking landers were mixed. Before the mission, scientists had established criteria to decide if life would be detected in the samples. The experiments actually met the criteria, but, unfortunately, some of the results indicated that biological activity may not be the best explanation for the observed results. The lack of finding organic molecules was one of the critical problems, though it is possible that Martian soil contains chemicals that can destroy organic molecules. Later, the Viking lander biological experiments were reproduced in laboratories on Earth using just inorganic chemistry. This led scientists to announce that no evidence of life on Mars was discovered in the experiments. However, there are still scientists who suggest that since the experiments gave results which suggested the possible presence of biological activity, life could have been present in the samples. It is also possible that the Viking landers touched down on areas particularly harsh on living organisms—the landing sites were chosen based on the ease of landing rather than the likelihood of finding life.

For more information on the Viking missions to Mars, visit http://www.nasa.gov/mission_pages/viking/