NOVA

Origins: How Life Began

PROGRAM OVERVIEW

NOVA reports on the different ways scientists explain how life emerged on Earth.

The program:

- relates the discovery of extremophiles—bacteria that thrive in harsh subterranean and deep ocean environments similar to those believed to have existed on primitive Earth.
- describes an attempt to determine when life began on Earth by searching rock formations in Greenland for higher-than-expected ratios of carbon 12 to carbon 13 (in ratios currently only known to be created by life processes).
- points to the comets and meteorites that struck Earth during its early history as possible sources for the carbon and other ingredients necessary for life to form.
- reveals the discovery of amino acids (organic acids that form the proteins that are essential to life) in meteorites.
- describes an experiment that simulated a comet's massive impact with Earth to determine whether certain amino acids could have withstood such a collision.
- indicates experimental results that show that the amino acids not only could have survived but also may have fused into peptides (compounds formed by linking two or more amino acids).
- speculates that life may have begun deep in Earth's crust or oceans, where it would have been protected from harsh solar radiation, the high temperatures of Earth's surface, and bombardment by meteorites.
- uncovers bacteria living deep below Earth's surface that obtain energy from methane, ethane, and propane gases and suggests that ancient bacteria might have derived energy in the same way.
- notes that surface bacteria that emerged following the Great Bombardment likely developed the ability to photosynthesize.
- looks at stromatolites—both modern ones built from layers of cyanobacteria and sediment and their fossil counterparts that may have formed the same way—and reviews the role the cyanobacteria played in creating an oxygen-rich environment in which complex life could form.

Original broadcast: September 28, 2004 PBS

BEFORE WATCHING

1 Have the class create a time line of major events using the program's 24-hour clock analogy. Draw two 12-hour clocks on chart paper. Ask students to imagine Earth's 4.6 billion-year history condensed into one day. Have students mark when think they the following occurred: formation of Earth's magnetic shield, creation of the moon, beginning of single- and multicelled life, and appearance of fish, insects, reptiles, dinosaurs, primates, and humans. Before they watch, assign students into groups to take notes on one or more of the above events.

2 Define "extremophile" (an organism that thrives under extreme conditions). Have students propose some environments on Earth where they think these creatures might live (in deep ocean environments near sulfur plumes, in Antarctic ice, in acidic hot springs). Discuss some advantages of being an organism in a harsh environment. (Extremophiles benefit by not needing to compete with other organisms for water, nutrients, and energy.)

AFTER WATCHING

1 Have students revisit their predictions about what occurred when and mark the correct places on the time line. How much did students' original estimates differ from when events actually happened? What parts of the time line are most surprising to students? Why?

2 Ask students to recall the scientists in the program (to help with recollections, find the program transcript at www.pbs.org/wgbh/nova/transcripts/3111_origins.html). Have students name the different specialties involved in studying how life began (geologist, biologist, chemist). What kind of evidence did each type of scientist find?

CLASSROOM ACTIVITY

Objective
To learn about what characteristics define an organism.

Part I

Materials for teacher
- dropper bottle with at least 100 ml of water dyed with green food coloring
- towels, cloths, or sponges for clean-up

Materials for each student
- 1 cm square of wax paper (15 cm by 15)
- 2 toothpicks

Materials for each team
- copy of the "Life's Characteristics" student handout
- copy of the "What Is Life?" student handout

Part II

Materials for each team
- copy of the "What Is It?" student handout
- hand lens
- 1 packet of Mystery Matter (regular baker's yeast repackaged in a plastic bag to conceal its identity)
- 1 tablespoon sugar
- 1/2 cup hot tap water (roughly 43 degrees C)
- 4 clear plastic bottles (4 oz.–16 oz.) with labels removed
- 4 balloons (15-inch required)
- measuring spoons (1/4 teaspoon, 1/2 teaspoon, 1 teaspoon)
- measuring cup (1/2 cup)
- funnel
- glucose strips

Procedure

Part I

1 Life is ubiquitous on Earth and appears in a diversity of forms. But what characteristics do organisms have? What makes them alive? This activity explores that question.

2 In the first part of the activity, announce to students that you have just received a supply of mysterious matter that you would like them to examine for you. Tell them that scientists are trying to determine if these are organisms and that you would like to know what students think.

3 Review with students the meaning of "organism" (living thing). For the purposes of this activity, a living thing is something that is currently alive or has once been alive, like a plant. A nonliving thing is something that is not alive and has never lived, like a rock.

STANDARDS CONNECTIONS

The "Life's Characteristics" activity aligns with the following National Science Education Standards.

GRADES 5–8
Science Standard C:
Life Science

Structure and function in living systems
- Cells carry on the many functions needed to sustain life. They grow and divide, thereby producing more cells. This requires that they take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or an organism needs.

Reproduction and heredity
- Reproduction is a characteristic of all living systems; because no individual organism lives forever, reproduction is essential to the continuation of every species. Some organisms reproduce asexually. Other organisms reproduce sexually.

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.

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.

Video is not required for this activity.

CLASSROOM ACTIVITY (CONT.)

4 Distribute the wax paper and toothpicks to each student. Create five to ten mounds of water (i.e., mysterious matter) on each student's sheet of wax paper by squeezing drops from a supply bottle. Make a variety of sizes—the smallest mound being one drop and the biggest five drops. Do not reveal that the matter is just colored water.

5 Ask students to investigate the droplets with their toothpicks. Have them list characteristics and behaviors they think could be found in organisms and those that seem non-lifelike. (See Activity Answer on page 5 for some examples of mysterious matter characteristics.)

6 Create a class list of lifelike and non-lifelike characteristics.

7 Organize students into teams. Distribute the "Life's Characteristics" student handout to each team. Have teams study the forest scene for organisms and further develop their list of characteristics of living things. As a class, expand the list of life characteristics begun earlier. You may need to help students understand that while some things (such as crystals, icicles, or fire) may seem to be alive according to a very simple set of characteristics (it moves, it reproduces), that life comprises a far more complex set of traits.

8 Distribute the "What Is Life?" handout. After having students read the handout, discuss how the mystery matter they studied and each of the organisms illustrated on the "Life's Characteristics" handout manifest the characteristics listed.

9 Now tell students you are going to give them a different type of mysterious matter that you also need categorized as living or nonliving. Distribute the Mystery Matter (yeast) and hand lenses to each team.

10 Ask students to examine a small sample of the matter with the hand lenses and record their observations.

11 Have students apply what they currently know about the characteristics of life to the matter to determine whether the Mystery Matter is alive. (As the yeast is dormant, it is likely that many students will say it is not an organism, that it is a dead organism, or that they do not know without further testing.) Ask students what other ways they can determine whether the matter is an organism. Some students might mention that organisms need food and water. Follow up by telling students they will test the matter to help determine if it is alive by providing it with water and an energy source and seeing what occurs.

STANDARDS CONNECTIONS

Grades 9–12
Science Standard C:
Life Science
Matter, energy, and organization in living systems

- All matter tends toward more disorganized states. Living systems require a continuous input of energy to maintain their chemical and physical organizations. With death, the cessation of energy input, living systems rapidly disintegrate.
- The complexity and organization of organisms accommodates the need for obtaining, transforming, transporting, releasing, and eliminating the matter and energy used to sustain the organism.

Classroom Activity Author
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CLASSROOM ACTIVITY (CONT.)

Part II

1 To test the idea that yeast will grow and reproduce under the right conditions, have students conduct the experiment as listed on their "What Is It?" student handout. Make sure you refer to the yeast as "Mystery Matter" until you reveal its identity in Step 5 below.

2 Distribute Part II materials listed to each team. (Note that you must use 15-inch balloons because the carbon dioxide produced by the yeast will quickly fill smaller balloons. Once the gas makes several balloons equally taut, it becomes impossible to tell which bottle produced the most gas. The 15-inch balloons have enough capacity so that only the most active yeast will completely inflate the balloons.) Review the activity procedure with students as outlined on their handouts. Have students conduct the activity, observing the bottles once they have prepared them and again after 24 hours. (The hot water, which is necessary to stimulate yeast growth, may initially inflate the balloons. This should dissipate when the water cools and further inflation will be caused by yeast respiration.)

3 After two days, have the class retest the two bottles using the glucose strips. Discuss students' observations. What did they see to indicate that the matter might be alive? (Bottles 2–4 had foam and inflated balloons, which could indicate respiration. The sugar depletion could signal energy uptake.) Based on what they have learned, what are students' final conclusions about whether the matter is alive?

4 Ask students if, based on the results of their experiment, there is anything else they would add to their list of life's characteristics. (They might mention that signs of life or past life are not always easy to recognize and that dormant and/or slow-growing organisms may appear to be nonliving unless observed under the right conditions or over long periods of time.) Many of the characteristics of life do not lend themselves to quick, one-time tests. Instead, they require multiple observations over a period of time. Earth's organisms exhibit many different ways to survive stressful conditions, such as periods with no food or water. Ask students what other tests they might conduct to determine whether the Mystery Matter is an organism.

5 Reveal that the Mystery Matter is yeast. Remind students that yeast is a kind of organism. Different members of this large group live in nearly every environment on Earth, including in and on humans.

6 As an extension, have students research definitions of life and try to establish a definition of life.

RELATED ACTIVITIES

Looking for Life in the School
www.pacsci.org/origins/
Test different locations in school for the existence of bacteria.

Microbial Survival!
www.pacsci.org/origins/
Expose bacteria to extreme environments to see how they survive.

Origins
www.amnh.org/education/resources/programs/origins/life.php
Discover how life survives in extreme environments and follow scientists who retrieve a stromatalite from the Saharan Desert in this American Museum of Natural History site that offers articles and student materials related to NOVA's "How Life Began" program.

ACTIVITY ANSWER

Part I
Mystery Matter Organism Characteristics

Lifelike Behaviors	Non-lifelike Behaviors
• follow a toothpick • eat by consuming one another • grow by merging together • reproduce by breaking into little potential organisms • have a firm, cell-like structure • are green, like plants • are shaped like cells • have a tough outer skin/membrane • move easily across the surface • contain water	• do not respond to the environment • lack internal structures • cannot move on their own • can become any size with no apparent consequence beyond size change • behave differently when not on a wax-paper surface (e.g., on the table)

Part II
Sample Results

Time	Turbidity	Froth	Balloon Inflation	Glucose
Initially	turbid after agitation	none	deflated	Bottle 1: none B2–4: present
30 minutes	turbid after agitation	Bottle 1: little/none B2–4: froth	Bottle 1: none B2–4: little/none	B1: none B2–4: present
60 minutes	solids settle out	B1: little/none B2–4: froth	B1: none B2: slight B3: medium B4: substantial	B1: none B2: depleted B3–4: present
24 hours	solids settle out	B1: little/none B2–4: froth	B1: none B2: slight B3: medium B4: substantial	B1–4: none

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LINKS AND BOOKS

Links

NOVA Web Site—Origins
www.pbs.org/nova/origins/
In this companion Web site to the program, find out how life could have started and why water is needed for life; read about the latest discoveries in origins research; use raw data to assemble the famous Eagle Nebula image; insert your own values into the Drake Equation; decode cosmic spectra, and more.

Astrobiology Education Poster: What Is Life?
nai.arc.nasa.gov/poster/
Includes three poster activities that address what life is, where it is found, and how to look for it.

Extremophiles
www.genomenewsnetwork.org/categories/index/environment/ext.php
Links to articles about extremophiles that thrive in cold, heat, metallic, methane-rich, radioactive, and salty environments.

Life on Earth ... and elsewhere?
nai.arc.nasa.gov/institute/library.cfm#epo
Links to a 60-page PDF that explores what life is, what it needs to live, what makes a world habitable, what extremes life can tolerate, and whether there might be life on other worlds.

Books

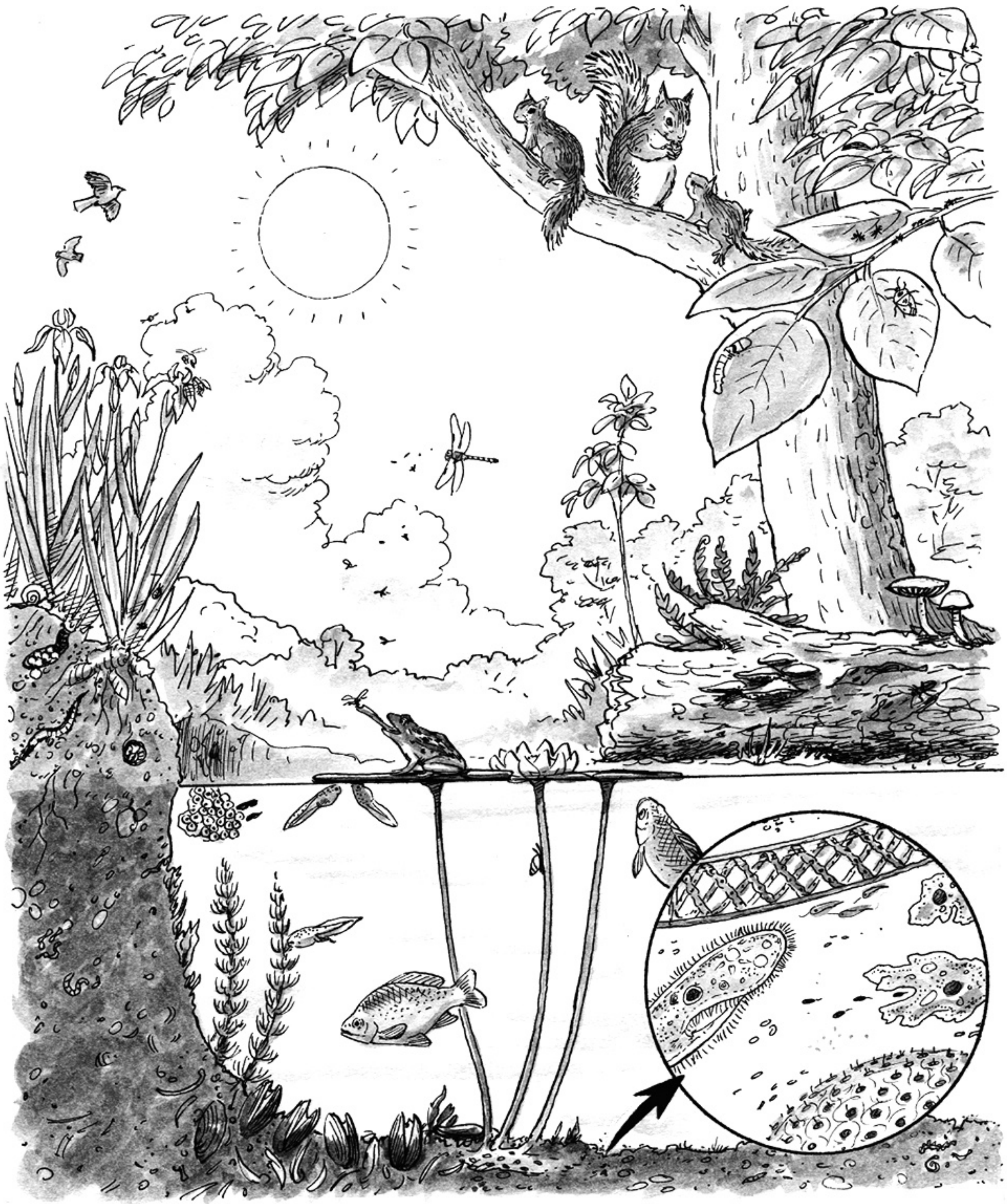
Breidahl, Harry.
Extremophiles: Life in Extreme Environments.
Broomall, PA: Chelsea House Publishers, 2001.
Details extremophiles, their environments, and the technology used to research them. Presentation caters to younger audiences.

Raymo, Chet.
Biography of a Planet: Geology, Astronomy, and the Evolution of Life on Earth.
Englewood Cliffs, NJ: Prentice-Hall, Inc., 1984.
Takes the reader on an illustrated and comprehensive journey across 4 billion years of life on Earth. Includes informational graphics.

Life's Characteristics

Look around you and you can see life everywhere. There are many forms of multicellular life, such as insects, birds, dogs, cats, and humans. But there are also many single-celled organisms, such as bacteria and fungi, that are invisible to the naked eye.

But what is this thing called life? What makes one thing alive and another one not? Look at the organisms in this illustration and see if you can identify the characteristics that show each organism is alive.



NOVA

What Is Life?

Surprisingly, there is no firm scientific definition of life. There is no single test that can establish the presence or absence of life nor one single characteristic that applies to all organisms. However, one can begin to define life by listing the characteristics that most living creatures share. For example, most of Earth's life forms exhibit the following traits:

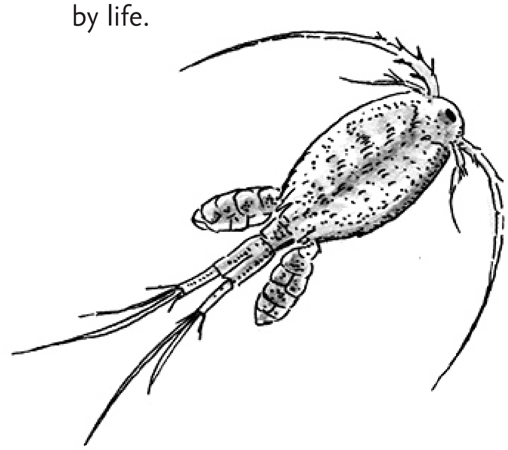
- have carbon-based chemistry.
- have a membrane or wall that creates an internal environment.
- use energy to maintain an internal state.
- require liquid water.
- are able to extract energy from the environment.
- carry out metabolic processes resulting in the exchange of gases and solid materials (i.e., consuming raw materials and producing wastes).
- exhibit some type of growth, cell division, reproduction, or replication.
- are able to undergo population evolution and adaptation to the environment.

Some nonliving objects, such as fire, possess many of these characteristics and some arguably living organisms, such as viruses, possess only a few. Are some characteristics more fundamental than others?

Two characteristics are particularly useful in helping distinguish living from nonliving things: the ability to reproduce (sexually or asexually) and the ability to produce and perpetuate genetic variation among offspring. Put another way, life is a self-contained chemical system capable of undergoing Darwinian evolution.

This large-scale, long-term view of life acknowledges that individual organisms must still carry out many of the small-scale, short-term functions listed above. In fact, many of the tests that scientists design to detect life on other planets look for byproducts related to these short-term functions. So while detecting life depends on finding many immediately recognizable characteristics, for life to persist on Earth, it must evolve and adapt to changing conditions.

Few of the characteristics on this list lend themselves to quick, one-time tests, and many require multiple observations over a period of time. Some Earth organisms leave traces after death. One way astrobiologists search for extraterrestrial life is to search for biosignatures—large-scale, telltale signs of life, such as the presence of gases produced by life.



Source:
Astrobiology in your classroom: Life on Earth...and elsewhere?
NASA Astrobiology Institute at nai.arc.nasa.gov/institute/library.cfm#epo

What Is It?

In this experiment, give your Mystery Matter something to eat and drink. Then, use your list of characteristics of life to decide whether you think it is an organism.

Procedure

1 Use the hand lens to take a close look at the Mystery Matter. Record your observations.
2 On a separate sheet of paper, make a chart like the one on this page titled "Experimental Results." Leave enough room in each category to record your observations for each bottle.
3 Number each of your four bottles and assemble the test setups as follows:
- place the funnel in the mouth of Bottle 1
- add the amount of mystery matter listed in the chart below
- add the amount of sugar listed in the chart below

Bottle	Mystery Matter	Sugar	Hot Water
1 (control)	1/4 tsp.	none	1/2 cup
2	1/4 tsp.	1/4 tsp.	1/2 cup
3	1/4 tsp.	1/2 tsp.	1/2 cup
4	1/4 tsp.	1 tsp.	1/2 cup

4 Repeat the above procedure using Bottles 2–4.
5 Use the measuring cup to pour the amount of hot water listed into each bottle and gently agitate each bottle to mix everything together.
6 Dip a glucose strip into Bottle 1. Record the results. Repeat with Bottles 2–4.
7 Squeeze all the air out of a balloon and slip it over the mouth of one of the bottles. Do the same with the remaining three bottles.
8 Gentle agitate the contents of each bottle to mix the materials. Make sure none of the materials remains clumped at the bottom of the bottles.
9 Record the appearance of the bottles. Predict what will happen in each bottle after one hour and after 24 hours.
10 After 30 minutes, gently agitate the contents of the bottles. Record your observations of the balloons and the contents. Repeat after an hour.
11 After 24 hours, record your observations of the balloons and the contents.
12 Remove the balloons. Test the bottles with glucose strips and record your results.
13 Provide an explanation for any changes you see. Using what you know about the charactertics of life, what can you conclude about the Mystery Matter?

Experimental Results

Time	Turbidity	Froth	Balloon Inflation	Glucose Presence
Initially				
30 min.				
60 min.				
24 hrs.				