Exobiology: A Biologist View of the Universe

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Overview

This unit is designed to compliment the gifted ninth grade syllabus in the Pittsburgh Public Schools. The connection between a first year biology course and cosmology may seem tenuous at first; however there is mention of the Big Bang in the mainstream Biology I curriculum.

There is no mention of either the origin of the universe or, more incredibly, the origin of man in the current text (Biology by Miller and Levine) adopted by the Pittsburgh Public Schools for the gifted biology students. In light of the current wording of the state objectives concerning evolution, it is perhaps even more critical that some such unit be included in the science curriculum.

Rationale

In a day and age when there are federally funded trips to Mars to search for evidence of extant or extinct life, the notion that we are alone in the universe is no longer a given. Students are bound to have questions about what type of life the probes are searching for, where did it come from, how will be identified , and what would it mean, if we were to find out that we are not alone.

The term exobiology was coined by Nobel Prize winning scientist Joshua Lederberg. What it means is the study of life beyond the Earth. But since there's no known life beyond the Earth people say it’s a subject with no subject matter much like say, string theory. It refers to the search for life elsewhere. It is also used to describe studies of the origin of life on Earth, that is, the study of pre-biotic Earth and what chemical reactions might have taken place as the setting for life's origin. We really don't know what the Earth was like three or four billion years ago. In the early 1950's, Harold Urey suggested that the Earth had a reducing atmosphere, since all of the outer planets in our solar system have this kind of atmosphere. The Earth is clearly special, in that it contains an oxygen atmosphere which is clearly of biological origin.

Both popular culture and the scientific community are replete with references to life on other worlds. In popular culture there are movies (E.T. the Extra-Terrestrial, Close Encounters of the Third Kind, AV P: Alien Verses Predator), books (The Man Who Fell to Earth, Contact, Chariots of the Gods) and television.

Meetings with sentient extraterrestrials have been imagined in countless storylines.

The contacts are either with an intelligent, musical happy being or a vicious, senseless killer, in between these two polarized views, every imaginable position in both the affirmative and the sceptically negative exists. There also exist a curious parallel between popular depiction of extraterrestrials and the political climate of the times. Thus Jimmy Carters “Close Encounters” becomes George W’s “War of the Worlds”.

In the scientific community there is the SETI Institute, whose mission is to explore, understand and explain the origin, nature and prevalence of life in the universe. The SETI Institute is a private, nonprofit organization dedicated to scientific research, education and public outreach. Founded in 1984, the Institute today employs over 100 scientists, educators and support staff. In the 1970s, the Viking mission to Mars provided information about the geology and weather on the red planet. The primary mission of the two robot space crafts was to determine if there was life on Mars. Conditions on Mars were thought to be far too harsh for large life forms. There is no liquid water on Mars and the atmosphere is very thin. During one day, the temperature on Mars may range from 10 degrees C to -80 degrees C. The large changes in temperature produce strong winds and planet-wide dust storms. Because of these conditions, scientists decided to look for microorganisms rather than large life-forms.

The Viking spacecraft conducted several experiments. In one experiment, samples of soil were taken from different locations. The soil samples were put into a nutrient broth that supported the growth of microorganisms on Earth. The amount of carbon dioxide in the broths was tested over a period of time.

Scientists were excited to discover that Martian soil produced carbon dioxide in the nutrient broth. However, the amount of carbon dioxide produced in the Martian soil was much smaller than the amount that would be produced by living things on Earth. The results of the Viking spacecraft experiments are not conclusive. Scientists were still not sure if life existed on Mars.

The Viking mission did not return a Mars rock sample to Earth. To study Mars rocks, a team of scientists at NASA Johnson Space Center and at Stanford University have been studying meteorites from Mars. The meteorites are igneous and have been collected on the Earth from 1815 to 1995. They all contain similar minerals, and many show evidence of interactions with liquid water. Because the Martian meteorites are all igneous rocks, they do not tell us as much about the Mars atmosphere and water as we could learn from studies of sediments and soils.

ALH 84001 is a meteorite, a rock that fell to Earth from space. It was found in December 1984 in Antarctica by a U.S. meteorite-hunting expedition. When it was found, ALH 84001 weighed about 4 and 3/4 pounds (1.93 kilograms). Scientists found microscopic shapes that resemble living and fossil bacteria on Earth; microscopic mineral grains like some produced by living and fossil bacteria on Earth; and organic chemical compounds that resemble the decay products of bacteria on Earth.

The Mars mission roving vehicles, Spirit and Opportunity as evidence of the continuing lure of evidence of life on other worlds. In a word rife with these extraterrestrial references it is only appropriate that the scientific and pedagogic communities join together to provide an informational foundation for the subject. Implicit in the study of exobiology are the biogenesis of life on other planets and the evolution of that life. Thus the study of exobiology can serve as a springboard to these two topics.

Objectives

The overall objective of this unit is to allow the student to imagine a vast universe that is not necessarily anthropomorphic in its nature. Specifically:

1. The student will be able to demonstrate a basic understanding of the origin of the universe and its structure.
2. The student will be able to employ the Drake equation.
3. The student will be able to describe the chemical parameters for life.
4. The student will be able to list methods employ in the search for life.
5. The student will be able to synthesize bioethical stances in regard with human interaction with other planets and other worlds.

Strategies

The unit will employ multiple teaching modalities. There will be a lecture portion for each section that is consistent with the college preparatory nature of the CAS course of studies. There will be one “wet” lab on coaservates as well as two group activities. Additional information will be provided by viewing the video “Life Beyond Earth”

Students will also be able to explore their creative side via activities such as: SETI and the Search for New Homes in Space.

Classroom Activities

Lesson One**:** The lesson begins with a power point presentation on the Big Bang Theory. Using diagrams drawings, notes and images, the Big Bang power point presentation is approximately 35 minutes in length with time built in for questions. The story arc of the presentation begins with a blank screen and an analogy is made to the lack of information provided by the universe before a Plank time had passed. The expansion of the universe will be next, followed by images from the Hubble Telescope that identifies the common structures in the universe that are visible to us and concludes with proposed scenarios for the future of the universe.

Lesson Two. The second lesson begins with selections from the video "Life beyond Earth" including the introduction and the section "The Habitable Zone".

In 1961, astronomer Frank Drake proposed a method of estimating the number of civilizations in our Galaxy that could be detectable from Earth. He wrote it as an equation, but it may be more useful to think of it as a series of questions: How many stars are born every year? What fraction of them has planets? How many planets does each such star have? What fraction of those planets can support life, and of those, how many planets actually give rise to life? What fraction of those living planets gives rise to intelligent beings? And of all those planets with intelligent beings, what fraction will produce radio transmissions that would allow us to notice them, and how long would they continue to transmit them?

Student will then break-up into groups of two to work on their laptops. Each pair of students will access the webpage for video and then go to the Drake equation page. Students will be asked to present three printouts of their work with high medium and low values for each of the variables that are part of the equation (5).

Lesson Three. This lesson will include a "Wet Lab" and require a double period to complete.

The purpose of this lab is to suggest that the origin of life might not require a supernatural affecter. While the gap between pre-biotic and the living condition is sizable, there have been several postulated bridges between them including clay particle substrates, microspheres, protobionts and coaservates.

Coaservates are spherical aggregation of lipid molecules making up a colloidal inclusion which is held together by hydrophobic forces. Coaservates measure 1 to

100 micrometers across and form spontaneously from certain weak organic solutions. Their name derives from the Latin *coacervare*, meaning to assemble together or cluster. It was suggested by Oparin that coacervates may have played a significant role in the evolution of cells. These entities could have been the precursors for life on earth.

The classic experiment demonstrating the mechanisms by which inorganic elements could combine to form the precursors of organic chemicals was the 1950 experiment by Stanley Miller. He undertook experiments designed to find out how lightning--reproduced by repeated electric discharges--might have affected the primitive earth atmosphere. He discharged an electric spark into a mixture thought to resemble the primordial composition of the atmosphere in a water receptacle, designed to model an ancient ocean, and amino acids appeared. Amino acids are widely regarded as the building blocks of life. Two of the essential scientific questions are what life, really, is and how did it begin? Scientists predict that on primitive Earth, the atmosphere consisted mostly of ammonia, water vapor, methane, and hydrogen. With exposure to intense heat, ultraviolet light, electrical storms, and other conditions, organic molecules combined to form membrane-bound droplets called coacervates. These may have been the precursors of the first living cells on Earth. If Mars could support life in its early history, then life probably formed on many other planets, too.

See Appendix 1

Lesson Four: Note taking

In the 1970's two very successful NASA missions sent 2 surface landers to Mars. What they found was a dessert -like strewn with volcanic ejecta and shifting sands. The Viking landers were equipped for three experiments designed to test for signs of life on the planet's surface. However, what would scientists be looking for? Would it be activity, water, waste?

The Gas Exchange Experiment (GEX) was looking for changes in the makeup of gases in a test chamber, changes that would indicate biological activity. The results from this test were taken to counter-indicate biology.

The **Labeled Release Experiment (LR)** was set up to detect the uptake of a radioactively-tagged liquid nutrient by microbes. The idea was that gases emitted by these microbes would show the tagging. Initial results were in line with this prediction but in the end, the overall results were inconsistent.

The **Pyrolytic Release Experiment (PR)** involved "cooking" soil samples that had been exposed to radioactively-tagged carbon dioxide to see if the chemical had been used by organisms to make organic compounds. Seven of nine experimental runs seemed to show small concentration of micro-organisms but the results were later discounted.

The **Gas Chromatograph -- Mass Spectrometer Experiment (GCMS)** also heated a soil sample and revealed an unexpected amount of water but failed to detect organic compounds.

Others have made similar experiments. A group at the Department of Chemistry and Biochemistry at the University of California, San Diego, exposed sulfur-bearing molecules like those thought to have been present before the Earth formed to low levels of light. The presence of the light was enough to generate organic compounds - molecules containing carbon, which form the chemical basis of life as we know it.

The landing site of the Mars rover Opportunity was once drenched with water, providing an environment that could have supported life, NASA scientists announced in 2004.

LESSON FIVE

The final lesson for the exobiology unit will be a scenario concerning communication with an intelligent race of extraterrestrial beings and to design a habitat that could support human life for a long (multigenerational?) space flight. It is in this section of the lesson that the students will be able to use their imagination to describe an extraterrestrial culture as well as plan their space flight. Communication with aliens is the holy grail of generations of humans who have looked to the empty night sky and asked if we are alone in the universe. The Voyager carried images and sound, radio and television waves have been propagating outward for decades and SETI has put together a supercomputer array to listen to the night sky. Although the response has been zero, we still wait eagerly for some type of response. It is in this realm that religion, evolution and metaphysics enter the fray. Though these activities students will be asked to articulate their views on man’s uniqueness in the universe.

Appendix 1: Plans are adapted from the PBS Life Beyond Earth video and web site.

Instructional Objectives:

Students will

1. study the work of scientists and determine how scientists test theories;
2. construct a model of coacervates, observe its characteristics, and compare them with the characteristics of living cells;
3. infer conditions that may have led to the formation of life.

Background Information:

Is there really life on Mars? Was there once cellular material on the red planet? Scientists have been studying these questions for a long time, and now they have some new information that may give some clues. Scientifically speaking, to study the controversy about life on Mars, it is important to understand what the work of scientists is all about. How do scientists develop a theory like life exists on Mars?

The easiest way to test the theory of life on Mars is to create a series of predictions that can be tested experimentally. If the tests support the predictions, then the theory will gain support; if the tests are inconclusive or do not support the predictions, then the theories will lose support.

Two of the essential scientific questions are what is life, really, and how did it begin? Scientists predict that on primitive Earth, the atmosphere consisted mostly of ammonia, water vapor, methane, and hydrogen. With exposure to intense heat, ultraviolet light, electrical storms, and other conditions, organic molecules combined to form membrane-bound droplets call coacervates. These may have been the precursors of the first living cells on Earth. If Mars could support life in its early history, then life probably formed on many other planets, too.

Time Needed for Activity:

Two periods

Materials:

Students will work in groups of two or four. Each group needs the following materials:

- Pencil and paper
- Reference information

For the coacervate lab:

- 5 ml 1% gelatin solution
- 5 ml 1 % gum-arabic solution
- 5 ml 1% hydrochloric acid solution
- Test tubes and stoppers
- Droppers
- pH paper
- Test-tube racks
- Compound microscopes with slides and cover slips
- 100 ml graduated cylinders
- Dilute red food coloring
- Light source

Procedures:

Part A. Is There Really Life on Mars?

Scientists have been studying this question for more than 25 years, and they have made many observations. Read following paragraphs and answer the analysis and conclusion questions.

In the 1970s, the Viking mission to Mars provided information about the geology and weather on the red planet. The primary mission of the two robot space crafts was to determine if there was life on Mars.

Conditions on Mars were thought to be far too harsh for large life forms. There is no liquid water on Mars and the atmosphere is very thin. During one day, the temperature on Mars may range from 10 degrees C to -80 degrees C. The large changes in temperature produce strong winds and planet-wide dust storms. Because of these conditions, scientists decided to look for microorganisms rather than large life-forms.

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One meteorite has some carbonate globules in it that look like ancient Earth fossils. These blobs, called carbonate rosettes, have cores filed with manganese and surrounded by iron carbonate the then by an iron sulfide layer. Bacteria in ponds produce similar rosettes. Organic chemicals, PAHs (polycyclic aromatic hydrocarbons), were found that could have been formed by primitive bacteria. Electron microscopes have also revealed tiny, teardrop-shaped crystals of magnetite and iron sulfide. Certain bacteria can manufacture similar crystals. The pictures of the globules look like tiny fossilized nannobacteria, which may be similar to early Earth bacteria.

After reading the summary of the information, have students do the following:

1. Make a list of each piece of evidence that the scientists have discovered.
2. From your understanding of the evidence, determine what predictions scientists have made.
3. Select one hypothesis or prediction and design the imaginary experiment or research projects that you think should be conducted to subject the prediction to scientific testing. Make certain that your proposal is realistic, and decide what evidence you would want to collect. (It is not possible to go back in time or travel at warp speed.)

Discuss their proposed experiments as a class. Predictions have no value unless they can be tested with scientific experiments or checked with existing evidence.

Part B. Coacervates: The Beginning of Life?

1. Work in pairs and wear safety goggles. Pour the gelatin solution into the test tube and add the gum-arabic solution. Stopper the tube, mix gently, and do not shake.
2. Remove the stopper, remove a drop of the liquid, and test its pH. Record any observations about the liquid in the tube.
3. Place 1-2 drops of the mixture onto a microscope slide, add a cover slip, and look for coacervates under low power. Observe the coacervates under high power and make drawings of what you see.
4. Add 2 drops of hydrochloric acid to the test-tub mixture and when it clears, prepare a new wet-mount slide as you did before. Before you add the cover slip, add a small drop of dilute food coloring and look for coacervates once again both under low- and high-power magnification.
5. Record observations and make drawings.
6. Look at prepared slides of bacteria and single-celled protozoan.

Questions:

1. What is the relationship between pH and the formation of coacervates?
2. What conditions in ancient oceans may have caused coacervates to form?
3. Compare and contrast the prepared slides of cells with your observations of coacervates.
4. If life is found on other planets, would it be similar to or different from life here on Earth? Explain your answer.

Appendix 2

The experiments: Describe and discuss

1. Carbon assimilation experiment (PR): In this experiment ^{14}C labeled CO_2 is admitted to a martian soil culture, any biological uptake is measured by pyrolytic analysis.)

2. Labeled release experiment (LR): In this experiment dilute solution of ^{14}C-labeled nutrient broth (formate, glycolate, glycine, D-alanine, L-alanine, D-lactate, and L-lactate) is added to see if uptake occurred.

3. Gas exchange experiment (GEX): detect release of gasses from Martian sample upon the addition of water, the assumption being that the martian microbes might simply be dormant.

B. The Results

1. PR detected carbon

2. LE showed CO_2, thought to be due to the reaction between formic acid in the broth and oxygen peroxide resulting from the reaction between the super oxides and introduced moisture.

3.GEX Initial results showed 15 to 30 times expected oxygen levels.

Appendix 3

Instructional Objectives:

Students will -

1. discuss the feasibility of intelligent life in the universe and propose methods of communication;
2. design a model community for space travelers and describe how the essential needs of the planetary biospherians will be met.

Background Information:

It seems that human beings have dreamed and wondered about the existence of extraterrestrial life capable of communicating with us. In the last 50 years, with the help of radio telescopes, we now have the capability of interplanetary communications.

Procedures:

Part A: What Would It Be Like If We Could Communicate with Other Life Forms?

Time Needed for Activity:
One half of a class period

Target Grade Level:
High School with minimal adjustments for middle level students.

Materials:

- Internet access in the classroom (optional)
- Paper and pencil
- Art supplies (if needed)
- Student science journals

Activity:

1. Discuss with students what they know about the existence of life elsewhere in the universe based on literature, TV, movies, and so on.
2. Determine how many in the class "believe" that extraterrestrials have visited our planet.

3. Have the students record in their journals how scientists would solve the problem of finding out if life exists. Remember, this process includes asking these questions:
    - What do scientists know? -- evidence
    - How do we know it? -- experiments and technology
    - What don't we know?-- limits of the data
    - What predictions can we make? what testing can we do
    - What questions can we ask, what experiments can we do, to find out? -- new investigations or missions
4. If possible, have the students find out more about SETI on the Internet and record their notes in their science journals.
5. Have students complete the following task and then share their results with the class.

The SETI radio telescopes have picked up several unusual radio transmissions from deep space. The analysis of the signals supports the conclusion that the transmissions originated from intelligent life in a distant solar system. You would like to establish communication with this life-form, and you must decide both the message you will send and the kind of communication you will use (digital, music, language, etc.). Defend your choice.

Part B. What Would It Be Like If We Could Live on a Different Planet or Moon in Our Solar System?

Time Needed for Activity:
One week of 50-minute classes, or if time is given for homework, one period to introduce the project and begin in class and one period at the completion of the assignment for in-class presentations of the group models.

Target Grade Level:
High School (Middle school students can complete this project but are not expected to have the detailed background knowledge presented in biology and environmental science courses.)

Materials:

Each group of four students will need the following:

- Student journal for note taking and preparing written explanations
- Butcher paper or poster board for illustrated models
- Art supplies as needed (scissors, markers, glue, colored paper, etc.)
- Video of Biosphere II (optional)

- Overhead transparencies and markers for student presentations

Activity:

1. Where would you like to live in the solar system if you could choose any place in space? Have each student group select a planet or moon in our solar system to be the site of its H.O.M.E. (Habitats Out of Manmade Ecosystems.) The group must gather information about the geology, climate, atmosphere, gravity, and access to solar radiation of their selected location.
2. Because they will be the first to colonize the planet/moon, student teams should brainstorm what supplies they will need to carry with them from Earth -- the essentials for life.

   (Optional) It would be helpful to show one of the many videos produced about Biosphere II and what research was completed to set up the self-contained habitat.

   They may select the number of homesteaders who will travel with them and what skills each person will have.

3. Design a blueprint of the habitat on the poster or butcher paper and include the following components: energy sources, essentials for life, waste treatment, transportation, communication, and matter cycles. Remind students that their biohabitat must be an all-inclusive environment that supplies water, food and fiber, land, minerals, technology, shelter, and a diverse gene bank of plants and animals. If resources are available on the planet or moon, then methods to extract them must be included. Microorganisms and medicinal plants should also be considered.

Assessment/Evaluation:

Each group will need to make a five-minute presentation of their H.O.M.E. During the presentations, each student in-class will evaluate the group presentations and provide positive feedback and constructive suggestions for ways to improve the project. Questions and answers should be allowed at the end of each presentation. At the conclusion of all the presentations, have each group conduct an evaluation of the project and the work of each team member. Did all students contribute? Did each individual complete his or her section of the project? Did everyone in the group contribute to the presentation?

Annotated Bibliography/ Resources

Bennett, Jeffery, Shostak and Jakosky, Life in the Universe Addison Wesley (2003) -
for introductory college courses for nonscience majors

Bond, R.J microorganisms on Mars, 156 Science 1436 (1967) – an interesting but dated look at theoretical exobiology.

Hawking, Stephen. *A Brief History of Time: From the Big Bang to Black Holes*. New York: Bantam, 1988 – no explanation needed

Horowitz, H, and G. L. Hobby, Viking on Mars: The Carbon Assimilation Experiment, Scientific Results of the Viking Project 4659 (reprinted from Jour. of Geophysical Res.) (Sept. 30, 1977)

http://www.astrobiology.com/exobiology.html - A portal to many other sites

Kluger, Jeffery E.T., Tou May be Home Already. Time. August 7, 2000. A good article about the relationship of extremophyles to exobiology.

www.pbs.org/lifebeyondearth Timothy Ferris in the scientific search for extraterrestrial life -- a companion site to the PBS documentary Life Beyond Earth**.**