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Astrobiology: The Final Frontier of Science Education

by Jodi Asbell-Clarke and Jeff Lockwood

Astrobiology seems to be all the buzz these days. It was the focus of the ASP science symposium this summer; the University of Washington is offering it as a new Ph.D. program, and TERC (Technical Education Research Center) is developing a high school integrated science course based on it. So what is astrobiology?

The NASA Astrobiology Institute defines this new discipline as the study of the origin, evolution, distribution, and destiny of life in the Universe. What this means for scientists is finding the means to blend research fields such as microbiology, geoscience, and astrophysics to collectively answer the largest looming questions of humankind. What it means for educators is an engaging and exciting discipline that is ripe for an integrated approach to science education. Virtually every topic that one deals with in high school science is embedded in astrobiology.

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What (or Whom) Are We Looking For?

Movies and television shows such as *Contact* and *Star Trek* have teased viewers with the idea of life on other planets and even in other galaxies. These fictional accounts almost always deal with intelligent beings that have evolved to a point of being able to communicate with humans. This is very appealing and makes for a great storyline, but in reality, it is much more likely that the Universe may be teeming with life on a much more basic level. Even on Earth, an overwhelming majority of the biomass with which we share our planet is in the form of microorganisms. So the first thing we have to do is understand what we mean by "life on other worlds" and figure out how to search for it.

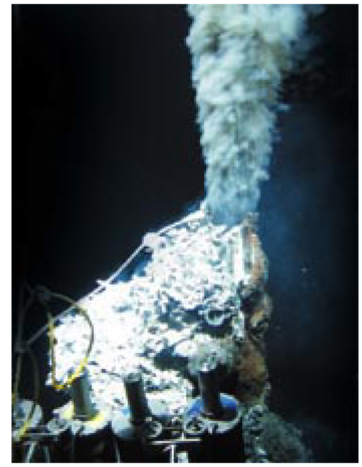
Earth is the only known case study, and we must take from it any lessons we can. Apparently, as soon as Earth was mature enough for life to form here, it did. We have evidence of microbial life dating back 3.9 billion years, over 80 percent of the entire lifetime of the planet. This is helpful since it means that someone searching for life on Earth would have had a long timeframe within which to find it. Searching for microbial life elsewhere may not be as easy as finding an alien knocking on our back door, but it certainly seems a more likely prospect.

Because we are not going to be able to observe microbes, or even human-sized creatures, on other planets, we have to look for secondary evidence of life, called "biomarkers." These include the trace gases and elements given off as byproducts of microbial life. For example, oxygen, detected in a planetary atmosphere or in an auroral discharge, would be indicative of plant life. Detecting methane or sulfur compounds might indicate energy processes of microbial life such as bacteria. By using spectroscopy and other remote sensing devices, we can search for these elements on bodies in our Solar System and perhaps in the future we will be able to detect these elements on the planets being discovered around other stars.

Where Do We Look?

One may be tempted to rule out various places in our Solar System as sites that harbor life because of their extreme conditions. Planets too far from the Sun seem far too cold and dark to host life, right? Not necessarily. We only have to look as far as our own terrestrial backyard to find contradictions to this intuition about life.

Extremophiles are creatures living at what are considered extreme conditions with respect to human life. Different life forms have been found on Earth at temperatures greater than water’s boiling point and below its freezing point, in high acid and base conditions, at 4 km below the land surface and at 6 km below sea level. Microbes have lived in space for years, unprotected from extreme radiation.



Deep ocean vents are essentially geysers on the ocean floor and are associated with areas of active seafloor spreading. Spewing hot, mineral-rich material into the frigid, surrounding water, such vents are known to harbor bacterial life. Photo courtesy of the University of Delaware College of Marine Studies.

A crucial example of life under extreme conditions resides in deep-sea vents first discovered in 1977. At depths of 2,100 meters on the floors of the Atlantic and Pacific Oceans, these chimney-like vents spew water heated by a geothermal energy source along with minerals that help support life forms such as tubeworms, clams, and shrimp. The water temperature reaches 750° F but does not boil because it is under tremendous pressure on the ocean floor.

At the other extreme, Lake Vostok sits 4,000 meters under the ice about 1,000 km from the South Pole. This lake provides an Earth-based laboratory that may provide great insight into what is occurring elsewhere in the Solar System. It is thought to have conditions similar to one of Jupiter’s moons, Europa. Lake Vostok is a unique and precious resource, and scientists must collect samples and pursue investigations without contaminating it. The introduction of any kind of evolved life form into Lake Vostok could perturb this ecosystem so that it no longer serves a purpose for astrobiology.

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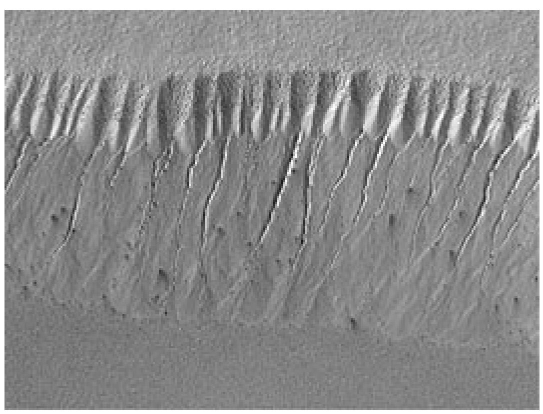
Lessons from Our Past

By understanding how life formed on Earth, astrobiologists hope to find clues on how to find life elsewhere. Biologists have long believed that Earth formed with only simple inorganic molecules such as hydrogen, methane, and ammonia in its atmosphere and crust. It was thought that energy from lightning storms instigated the creation of the complex organic molecules containing carbon, hydrogen, oxygen, nitrogen, potassium, and sulfur (CHONPS) that are attributed to life on Earth. But recent discoveries are opening minds to other possibilities.

It has previously been believed that our Solar System began from a cloud of simple molecular gas, and only as Earth evolved did complex organic molecules form. However, recent observations of the atmospheres around old carbon stars show the existence of organic molecules. As these stars die, they spew organic molecules out into the interstellar medium where new stars form. The formation of a new star may include a planetary system with Earth-like planets that in turn will contain organic molecules right from the start.

Another theory points to a Martian meteorite, known as ALH84001, discovered in an ice field in Antarctica. Although this 4.2 pound piece of rock is thought to have landed on Earth about 13,000 years ago, it was ejected from Mars 16 million years ago and radioactive dating shows that it formed about 4 billion years ago at a time when Mars was much warmer and wetter.



Observations by the Mars Global Surveyor indicate areas of liquid water run-off—perhaps even in the very recent past. In this image it appears that water has seeped from beneath the Martian surface and run down the steep gully walls. Image courtesy of NASA/JPL/Malin Space Science Systems.

The Search Is On

To find life elsewhere, we must first find homes for life on Earth. Mars has long been a place of study, originally because of it being our neighbor and thus the fodder for many a science fiction story, but also when the surface of Mars was photographed and mapped by spacecraft beginning with *Mariner*, those stories became more than fantasy. Channels on the surface of Mars seem to give clear evidence that water once flowed there and that the planet was once much warmer than it is now.

The *Galileo* spacecraft sent to explore Jupiter has rekindled great interest about the possibility of life on its satellite, Europa. A large ocean of liquid water is thought to exist under the moon's icy surface as evidenced by the recently discovered periodic fluctuations of Europa's magnetic field. Regions of "chaotic" terrain may represent periodic episodes of crustal melting, which could allow for the exchange of nutrients and gases necessary for the propagation of simple life forms. There is also evidence that the ice layer covering the ocean may be fairly thin, only one or two kilometers thick. This can be inferred from the cycloidal crack patterns that scientists have determined are caused by Jupiter's intense tidal pull.

Microbial life is known to exist in Europan-type conditions on Earth, and studies of Lake Vostok will enlighten future explorations for life in our Solar System. In addition, the *Cassini* spacecraft is hurtling toward Saturn where in 2004 it will be able to examine the ringed-planet's large moon Titan, long a prime site for scientists' speculation about life.

Europa's complicated surface appears to betray the presence of an ocean of water beneath the ice. In this image from the Galileo spacecraft, the ridged plains are likely evidence of cracking and then refreezing of the Jovian moon's icy surface. If there is, indeed, a deep ocean under the ice, do conditions for at least unicelluar life obtain on Europa? Image courtesy of NASA.

But we are no longer limited to the nine planets around our Sun for future investigations. In the past few years, about 50 planets (and counting) have been discovered around other stars in our Galaxy. These planets were first discovered by detecting the "wobbling" motion of the central star as it was drawn to and fro by the gravitational pull of the orbiting planet. For this reason, the detection mechanism is biased toward massive planets; so not surprisingly, many planets of roughly Jupiter's mass have been found.

Astrobiologists are spreading their wings and searching in many different modes, for many different possible types of life. One of the most exciting is the Search for Extraterrestrial Intelligence (SETI). Since the early 1960s, a small group of astronomers has been searching the skies for a signal from another civilization. In 1994, Congress cut the government funding for this research, and a new effort, Project Phoenix, rose from the ashes with support from private funding. Currently, Project Phoenix is monitoring Sun-like stars over a range of radio frequencies and is looking for a signal that is limited to one very narrow-band frequency. This type of signal would almost certainly have to be sent deliberately as opposed to being caused by a natural phenomenon.

What Does the Public Have to Learn from All This?

The research scientists aren't the only ones getting excited about astrobiology. This new discipline has tremendous potential for revolutionizing science education. It is rich with exciting content to engage those who generally don't consider themselves scientifically-oriented, and also for opening the ears and minds of adults who may want a new reason to visit their local science center.

High school courses have traditionally been compartmentalized into biology, chemistry, physical or earth science, and perhaps physics or an elective such as astronomy or oceanography. This may, in the best of cases, prepare students for the "almighty test," but does it really prepare students for scientific literacy and logical decision-making? In many cases, the current educational system is failing to prepare students even for its own tests because students' interest and engagement in science is waning. They see no connection between what is taught in textbooks and what they value in their own lives.

Science in the real world is integrated and problem-based. We need to "hook" students. We need to offer a course so inherently interesting, and, yes, even mysterious, that students will open their minds and let us insert a gentle wedge to begin the learning process. Astrobiology is such a subject, a portal to understanding broad scientific concepts in a context that is immediately exciting and intriguing for students.

Full-year astrobiology courses in the works include the integrated high school science curriculum "Astrobiology: The Search for Life," being developed by TERC and NASA (astrobio.terc.edu), and another, written around the theme of evolution by the SETI Institute and NASA, "Voyages Through Time" (www.seti-inst.edu/education/vtt-bg.html). In addition, the Center for Educational Technologies at Wheeling Jesuit University, in conjunction with the NASA Classroom of the Future, is producing a software program called "Exoquest" (http://www.cotf.edu/ExoQuest/) for grades 7–9 that will create a link between students and scientists to pursue investigations in different areas of astrobiology research. A new Ph.D. program has also been created at the University of Washington, Seattle, specializing in astrobiology (depts.washington.edu/astrobio).

These are just a few of what will be a wave of exciting educational opportunities. The courses and programs meet the challenge of preparing young people for new types of research, those that require multiple perspectives and integrated problem-solving skills. They are also just in time to prepare the next generation to use the rapidly advancing technology that will allow us to unravel many of the puzzles the Universe offers us. It is only a matter of time until one of these well-prepared students discovers the first evidence that we are not alone.

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A High School Curriculum in Astrobiology

Astrobiology is a truly integrated science. For example, when extreme environments of Earth are examined as a springboard to the search for life in the Solar System, other subjects–the biology of microorganisms, the chemistry of nutrients, the process of respiration, and the nature of autotrophic habitats–are intimately entwined and must be considered in one breath, albeit a long one. When the subject of the search for life around other stars is undertaken, it is impossible to separate the discussion of instrumentation and technology from the nature of radio waves from the size and scope of the Universe.

As a science, astrobiology is a perfect vehicle for introducing major science content standards. Not only can they be threaded through the curriculum, but they can also be applied by students within the context of a problem that they need to solve. For instance, the electromagnetic spectrum can be introduced in one section of the course in terms of white light necessary to see astronomical objects with our eyes and telescopes, and in another section, infrared light can be studied as a tool to discover planets orbiting other stars. In yet another, radio waves are used to attempt communication with life forms in other solar systems. In each case, repeated application of a concept within the context of solving a particular problem creates a powerful conceptual learning sequence for students.

Other important national science education content standards are nested within the branches of the astrobiology subject matter tree: atomic and kinetic-molecular theory, diversity of life and evolution, chemical species and reactions, thermodynamics, fundamental forces, cell theory, photosynthesis and respiration, and the nature of light and electricity.

The search for life, with all its cross-curricular ties, is also rich in potential long-term student research projects. Students can immerse themselves in a variety of astronomy-, biology-, and chemistry-related disciplines. Students can examine and measure the crater distribution in the northern plains of Mars, seeking evidence for large bodies of water sometime in the distant past or attempt to unscramble the maze of cracks and ridges on Europa. Teachers and students can easily set-up and perform bacteriology experiments such as testing for the presence of life in "extreme" Earth environments (hot desert sands, snow banks, icy water) using disposable petri dishes and instant agar. One approach is to have students try to prove that life does not exist in a place of their choosing. Taking swipes from the middle of barren parking lots or from automobile tires and then inoculating plates to produce thriving bacteria colonies every time reveals much to students about the tenacity and diversity of life on Earth.

Growing plants under different sets of environmental conditions, using lunar- or Martian-like soils, can give students a feel for the problems that will attend space colonization and terraforming other worlds. Astrobiology offers a wide spectrum of projects to satisfy students' particular interests. And as Project 2061 and the national and state science education standards insist, students need to do science instead of take science in order to develop that spark of interest and excitement that results in the quest to understand the unknown.

To accomplish this goal, TERC (Technical Education Research Center, Cambridge, MA) and NASA are developing an interdisciplinary middle and high school course using astrobiology as its unifying, underlying structure. Through investigations based on the search for life on other planets, students will explore diverse concepts in chemistry, biology, physics, Earth and space science, and engineering. They also develop research skills such as hypothesis testing, experimentation, fieldwork, modeling, and image data analysis, and engage in long-term experiments. The astrobiology course will provide students opportunities to master fundamental science concepts in a relevant context and apply their skills and understanding directly in a variety of investigative modes. In short, the students taking this course will feel as if they are partners in the quest for knowledge as they explore the many disciplines contained in a branch of science that may soon yield some of the most important scientific discoveries of all time.