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Astrobiological Themes for Integrative Undergraduate General Science Education

by **Bor Luen Tang**
National University of Singapore
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Abstract

Astrobiology, or exobiology, is defined by NASA as "the study of the origins, evolution, distribution, and future of life in the universe." The subject has an aura of the mysterious and the unknown. It is, however, a valid field of scientific investigation. The absence of extraterrestrial life is a falsifiable hypothesis, and astrobiology is much more than looking for extraterrestrial life. Its practicing front represents the pinnacle of multidisciplinary research and engages experts from fields as diverse as microbiology and physical geology, and the study of astrobiology encompasses endeavors ranging from cosmological modeling to genetic analysis. The subject of astrobiology is broad and transcends research boundaries. As such, astrobiology is ideally suited as a platform for an integrative approach to undergraduate general sciences education, with non-science majors as the target audience.

1. INTRODUCTION

General science education modules targeting non-science majors are difficult to design and tend to be overly specialized. In many universities, including my own, undergraduates with intentions to major in humanities or business are required to take modules offered by different science departments. A good number of students complete these courses merely to fulfill credit requirements. Even if sufficient facts are understood, memorized, and reproduced to pass examinations, many students fail to fully appreciate the excitement and beauty of science and scientific research. This indifference can be observed among science majors as well. To enhance interest and understanding, science educators have often tried to build foundations and concepts of various subjects in order to relate them to relevant issues in everyday life, but these attempts have had their limits. Another problematic issue of general science education is how to present the diverse subjects in the sciences within the limited allocated time in an integrative manner. It should be clear that it is important to instill in non-science majors a lasting interest in, enthusiasm for, and an understanding of fundamental concepts in science, which any modern person should have. The importance of this is particularly relevant when considering that some of these students will become administrators and political leaders with a profound influence on how scientific research will be pursued and funded in the future.

2. ASTROBIOLOGY: LIFE IN THE UNIVERSE

Though lacking in direct evidence, the notion of a universe teeming with life excites scientists and laypersons alike. A great many activities have contributed to the birth of, and advances in, the field of astrobiology. Although the notion of the possible existence of extraterrestrial life has been around for a long time, particularly in the realm of science fiction, the subject of astrobiology emerged as a full-fledged scientific discipline only in the last 30 years or so. The hard science of the field has its roots in the various space exploration programs to the Moon, inner planets, and the Galilean system. These include explorative one-way journeys, such as those undertaken by the Pioneer and Voyager spacecrafts, and outright attempts to look for life on a planet, such as that attempted by the Mars Viking mission.

Over the years, generous NASA funding (Strick 2004) has engaged the effort of numerous scientists interested in a variety of related ventures of astrobiological relevance. These range from studies of life's origins on Earth by organic chemists, biochemists, and microbiologists (Lazcano & Bada 2003; Orgel 2004) to the scanning of cosmic radio signals for possible extraterrestrial intelligence by radio astronomers (Tarter 2001). The field of astrobiology has more recently opened up, with observations of a multitude of microorganisms thriving in deep-sea hydrothermal vents and other environments with extreme temperature, pH, salinity, and pressure (Rothschild & Mancinelli 2005). These extremophiles indicate that life is much tougher and could therefore be more ubiquitous than we have previously thought. Flybys of the Jovian system by Voyager and Galileo, and Mars orbiters conducting planetwide observations of the planets have returned vast amounts of information, as have the recent landings on Mars by Spirit and Opportunity, and on Saturn's moon Titan by Huygens. It is becoming increasingly clear that some of these alien environments have terrestrial analogues and could harbor microbial, or even metazoan-like, life. Furthermore, advances in astrometric techniques have led to the rapidly growing list of extrasolar planets. Advances in interferometric imaging techniques could allow the direct visualization and spectroscopic inspection of some of these planets in the near future. All these new discoveries have fueled the burgeoning field with multiple fronts of research interests and opportunities.

The youthful excitement in the field of astrobiology has much to offer as an illustration of how science is pursued by both brilliant, driven individuals and big government-backed scientific enterprise. Its appeal lies not only in its breadth and range but also in the enormous promise of making findings that could change our perception of the universe in fundamental ways. This excitement is clearly illustrated by astrobiological articles of all kinds making the pages of premier journals such as *Nature* and *Science*. New international journals specifically devoted to astrobiology have also appeared in the last few years in the form of *Astrobiology* (Mary Ann Liebert Publishers) and the *International Journal of Astrobiology* (Cambridge University Press). The *Anatomical Records*, a classical review journal of biomedicine, recently devoted an entire issue (Volume 268, Issue 3) to a compendium of articles with an astrobiological slant. More recently, in a paper that is the first of its kind in *Current Opinion in Biotechnology*, James Staley discusses the promise of astrobiology as an integrative approach for science and engineering education and research (Staley 2003). Increasing numbers of papers with astrobiological themes are also appearing in traditional Earth sciences journals. New journals such as *Geobiology* (Blackwell Publishing), *Biogeosciences* (an e-journal of the European Geological Union, http://www.biogeosciences.net) and the *Journal of Geophysical Research: Biogeosciences* (American Geophysical Union) all have sections devoted to astrobiological papers.

2.1 An Integrated, Problem-Centered General Science Curriculum

Following is a suggestion of how science, in the context of a course in general education, can be taught in an integrative manner based on the main themes of astrobiology. As defined by NASA, the subject is "the study of the origins, evolution, distribution, and future of life in the universe." A general science course based on astrobiology can therefore be broadly divided into the three topics, as indicated below, that are relevant to more traditional fields of the physical, life, and Earth sciences.

1. Definition and Origins—Physics, cosmology, organic chemistry, biochemistry, cell biology, paleontology
2. Evolution and Distribution—Physical and historical geology, ecology/evolution, environmental science
3. Futures—Space science and technology, radioastronomy

All three of these broad astrobiological topics can be used in a problem-centered learning approach. The question of the origin of life, a fascinating yet unresolved problem, is a founding (and remains a major) subfield of astrobiology. From a pedagogical point of view, the origin-of-life problem could serve very well as a link to many fields of contemporary physical and life sciences. An approach to the problem, even at the introductory level, could instill appreciation of key concepts regarding the origin of the universe, the creation of heavy elements during the life and death of stars, and basic organic chemistry/biochemistry and microbiology. A descriptive illustration of Carl Sagan’s claim that "We are star stuff" entails an introduction to basic cosmology and an appreciation of fundamental concepts in Big Bang nucleosynthesis and stellar evolution. The modern definition of life is an entity capable of sustenance, growth, replication, and evolution (Koshland 2002). The instructor can easily relate and illustrate basic concepts of intermediary metabolism, cell division cycles, and molecular genetics associated with the various features of the above definition. Moving along, students may be led further to comprehend certain chemical concepts, such as the fundamental importance of redox-based reactions (Pace 2001), and cell biological concepts, such as the essentiality of the cell membrane and the utility of the RNA (Joyce 2002) in living cells. These topics may be better understood than when they are taught in a conventional curriculum because the consideration of these concepts in the face of a problem enhances deeper thinking and better consolidation of facts.

Likewise, the relevant knowledge and concepts in the Earth sciences, ecology/evolution, and environmental science can be addressed as the instructor discusses the geological evolution of the Earth’s surface and fossil evidence of life. This may be followed by an excursion into the various theories of how life may arise from abiotic chemistry, continuing on to the emergence of complex life forms from simpler ones, perhaps with a look at the tree of life and its construction based on DNA homology (Woese, Kandler, & Wheelis 1990). Students get a broad "Earth systems" view instead of the rather narrow, focused scope characteristic of conventional pedagogy. Such "big picture" appreciation is invaluable. Extinction events and their possible causes constitute a particularly effective illustration of ecological disasters. It is anticipated that most students will be moved by descriptions of the plausible events, particularly that of a cosmic projectile, that led to the demise of the dinosaurs. That the demise of such majestic beasts actually made way for the emergence of mammals, culminating in the arrival of man—the dominant species on this planet with cognitive intelligence—is an unrivalled illustration of evolutionary forces at work. On the other hand, a closer look at the controversy over the fossil evidence for early life provides an illustration of how scientists question each other's findings and how the process of scientific discovery is perpetually self-correcting (Brasier et al. 2002).

Any discussion of the future of life in the universe would be speculative, and topics to be taught based on this question may vary according to needs and preferences. A good approach may be to distill and present the most recent advances in biomedical and biotechnological sciences and to speculate on how these might affect our species and our civilization. Life can be considered in much broader terms, both in a social and a philosophical sense. Students may be encouraged to ponder the possibility of finding life elsewhere, to debate Christian de Duve's philosophical concept of life being a cosmic imperative (De Duve 1996), and to discuss the various means of how this might be achieved by the concerted efforts of our social and scientific enterprises. A discussion on Fermi's paradox would bring forth some technical aspects of our attempts to search for or contact extraterrestrial intelligence (SETI). Students could also be introduced to the various ethical problems and projected dilemmas pertaining to contact with alien life forms. Speculation on the forms that advanced civilizations might take and the technology that these societies could conceivably build (e.g., a brief overview of topics such as Dyson spheres [1959]) would excite those with technological inclinations. A particularly sobering fact that would make a good topic for explorative discussion is the demise of our own Sun at the end of its main sequence existence and how our civilization might deal with the situation when it is upon mankind. In contemplating these issues, students could be left with a sense of wonder and fascination beyond what could be achievable by conventional approaches.

One of the considerations of conducting a general science course is the question of integrating biology into some foundations in the physical sciences. This integration appears to be achieved fairly easily with a discussion of astrobiology. It would be natural to include the physical principles of optics and thermodynamics, for example, in the discussion of such concepts as stellar or galactic habitable zones. When covering the topic of organic molecules in interstellar cloud and comets, the photochemistry occurring in Titan's atmosphere, or the runaway greenhouse effect on Venus, fundamental chemistry concepts would be imparted. Students would welcome these physical and chemical concepts because they would immediately see that grasping these concepts is necessary to understanding what is going on. Another important advantage is the apparent seamless incorporation of introductory knowledge and concepts into Earth and environmental science topics. For example, surely the case of Venus as an extreme scenario could drive home the potential danger of anthropogenic global warming.

Staley (2002) stated that the multidisciplinary nature and appeal of its subject matter makes astrobiology ideal for integrating the teaching of science at all levels in educational curricula. It would, in fact, be particularly useful in designing a general science course to be taken by future (or even current) administrators, policy makers, and government leaders. Even traditional courses in undergraduate-level astronomy with a strong emphasis on physical aspects would benefit from incorporating a module on astrobiology.

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110 - 114