Chapter 1.4

Astrobiology as a medium of science education

Sun Kwok

1.4.1 Astrobiology as an interdisciplinary approach of teaching science

Astrobiology is the study of the origin, evolution, and distribution of life in the universe. Through the study of how life developed on Earth, we extrapolate this knowledge to extraterrestrial objects and speculate on how life could have developed under different conditions. Using remote observations with telescopes and direct physical experimentation with space probes, we are actively searching for evidence of life beyond the Earth.

Living organisms on Earth are made of cells, and their constituents can be broken down into carbohydrates, lipids, proteins, and nucleic acids. These biomolecules are made of chemical elements, which origins are found in stars. The present life forms on Earth are the result of billion years of biological evolution, which occurred through periods of geological transformation of the Earth. The emergence of life altered the composition of the Earth's atmosphere and the biological evolution on Earth was interrupted by external events such as cometary and asteroid impacts, resulting in major extinctions. Earth, being one of the four terrestrial planets, was formed out of solid debris of the primordial solar nebula, which are remnants of interstellar clouds and stellar ejecta. The birth to death life cycles of stars are part of the galactic evolution and cosmic evolution of the Universe.

Astrobiology is an interdisciplinary subject which draws from research in astronomy, biology, biochemistry, chemistry, geology, microbiology, physics, and planetary science. It also touches upon the disciplines of history, philosophy and sociology. Education in astrobiology therefore helps students develop the awareness that all sciences are related. Astrobiology studies the origin of life on Earth and the search for extraterrestrial life (biology), both are governed by universal physical laws (chemistry) but could develop under different rules of biochemistry. The evolution of life on Earth occurred in a changing physical environment (geology), which has been influenced by external events in the Solar System (planetary science). The Earth has changed greatly over time as the result of interactions between the crust, oceans, and atmosphere (earth system science and global change). Life on Earth must adjust constantly to adapt to these changes in order to survive (ecology). In a larger context, Earth is just a rocky planet which have billions of counterparts all over the Galaxy (astronomy). The possible existence of extraterrestrial life and the potential consequence of contact with alien civilizations has major social implications (sociology, philosophy).
Study of astrobiology therefore gives students a broader view of science than traditional science courses and offers them a grand perspective of the frontier of science.

1.4.2 Astrobiology as a vehicle to broaden the mind

While many students have the perception that science is dull and boring, astrobiology discusses topics that are of great interest to students and the general public. One example is extraterrestrial life. Most people have a simplistic view of extraterrestrial life, assuming it to be similar to ours and the inhabited extraterrestrial worlds having similar geological structures, climates, and daylight cycles to those of the Earth. This naïve view is commonly depicted in popular science fiction novels and movies such as *Star Wars* and *Star Trek*. Astrobiology offers an opportunity to look deeper into these issues. Our science explores and shows that there are many possible evolutionary paths to life, and extraterrestrial life may have totally different appearances from terrestrial living organisms. Exoplanets that harbor such life may have diverse atmospheric and surface conditions, as well as different daily and seasonal arrangements from Earth.

Unidentified Flying Objects (UFO) is another very popular topic. Many assume that aliens visit us in mechanical flying objects with shining visible lights. Through the study of biological and cosmic evolution, students in an astrobiology class will learn that any visiting alien civilizations will be much more advanced than us and their methods of visit are likely to be done in ways that are well beyond our present technological knowledge.

The above two examples help illustrate the common pitfalls in popular thinking. Scientists are conservative in their methods, but bold in their imagination. Others are careless in their methods, but conservative in their interpretations of observed events.

The study of astrobiology also forces us to seek deeper and more fundamental meaning of seemingly obvious concepts, such as the definition of life. Although the distinction between life and non-life seems institutively self-evident, a precise scientific definition that can be broadly applied to extraterrestrial life is not simple (see Chapter 1.1).

The study of alien worlds may have impacts on the understanding of our own Earth system. Our present awareness of global warming originated with the study of the greenhouse effect on the atmosphere of Venus. Will observations of other planets and planetary satellites help us learn more about past and future climate changes?

There are obvious religious implications on the question of extraterrestrial life. Does the existence of extraterrestrial life, in particular intelligent life, cause any conflict with existing religious doctrines? If such life exists, are humans really a chosen people created by God? Astrobiology can also have a linkage to the past. If advanced intelligent civilizations are indeed common in the Galaxy, would they have already visited us? Is there any anthropological evidence for past visits by alien civilizations? It is possible that alien civilizations did visit the Earth without us knowing it (Shklovskii and Sagan 1966)?

The exploration of other worlds by humans also raises ethical, political, and economic issues. Is it within our rights to visit, and possibly contaminate, other worlds? Should we be allowed to exploit the resources in the Moon and other planetary bodies? Will our visits to asteroids, planets and planetary satellites disrupt the environment of these objects to the extent that it is irreversible? If we send returning probes or humans to other planets, we could be bringing back alien life forms that may pose danger to life on Earth. Colonization of Mars may require us bringing Earth-based plants and other species to the planet; what are the potential consequences? What kinds of safeguards or precautions we should exercise before engaging in these activities (Chon-Torres 2017)? Given the current high public interest in human inhabitation of the Moon and Mars, we need to have a thorough discussion on these issues before embarking on such endeavors.

The study of astrobiology can also serve as a vehicle for the discussion of possible development of human society in the future. Over the last decade, we have seen tremendous progress in artificial intelligence. Will it come a time that there will be no distinction between natural and artificial intelligence? Will our world be taken over the intelligent machines? What will be the role of humans in such a society?

On a longer timescale, should humans be engaged in planetary engineering? It is conceivable that we could alter the atmosphere of Venus to make the planet habitable. Chemical or biological means can be introduced to convert carbon dioxide in the Venus atmosphere to oxygen, so that the surface temperature can be lowered and oxygen be available for human respiration. Is planetary engineering inherently different from the way that we have transformed planet Earth in the last several centuries?

The above examples show that astrobiology can be an excellent forum to bring students in humanities, social sciences, engineering, and science together. A course in astrobiology will challenge students' minds and open their imagination to wider perspectives.

1.4.3 Astrobiology and our place in the universe

Humans have asked the question: "How important are we?" since the beginning of our existence. The search for answers to "where is our place in the Universe" began as early as humans develop the intellectual abilities to think and this quest is still ongoing. Five thousand years ago, our ancestors have already begun careful observations of the heavens, and recognized that celestial objects have regular patterns of behavior and are highly predictable. Extensive ancient monuments were constructed to mark the repeatability of celestial events such as the extreme north and south positions of sunrise and moonrise positions (Selin 2000).

The search for the relationship between Heaven and Earth and the place of humans in it was the greatest driver for the development of intellectual thought. Through the use of simple observing instruments, our ancestors were able to achieve a highly sophisticated degree of theoretical understanding of the Universe. Over 2000 years ago, ancient thinkers already knew that the Earth was round and is a free-floating object in space not attached to anything. They also knew that the Sun's motion through the stellar constellation along the path of the ecliptic was responsible for the seasons. By adopting a model that puts a spherical Earth at the center of a giant celestial sphere upon which all stars reside, ancient astronomers were able to accurately predict the positions and times of sunrise and sunset at all locations on Earth. Ancient astronomers knew that the Moon shines by reflected sunlight and the phases of the Moon are the result of geometric relationship between the Sun, the Moon, and the Earth. Through observations and mathematical analysis, Greek astronomers were able to estimate the physical sizes of the Earth and the Moon, and the distance to the Moon to great degrees of accuracy (Kwok 2017).

The integration of Ptolemy cosmology, Aristotle natural philosophy and Christian doctrines gave rise to a model that humans are located between Heaven (which is located outside of the celestial sphere) and Hell (which is located in the middle of the Earth). This system of belief was only challenged after the proposal of the heliocentric model of the Universe by Copernicus (Kuhn 1957, Koestler 1959). The realization that Earth is just one of the planets and the possibility of existence of other worlds similar to our own as raised by Giordano Bruno greatly weakened the foundation of the Christian faith and the authority of the Church.

Recently, we are able to go beyond the model of the physical structure of the Universe and insert the scientific study of life into the question of search for our place in the Universe. The origin and evolution of life is considered in the context of the physical Universe. We now believe that the Earth is a tiny speck of dust in the vicinity of an ordinary star, one of about 100 billion stars in our Milky Way Galaxy, which itself is just one of one hundred billion galaxies in the Universe. We have learned that planets are common in our Galaxy (Lissauer et al. 2014, Kaltenegger 2017), and organic compounds are widely present in the Universe (Kwok 2011).

The fact that the building blocks of life are ubiquitously present suggests that life could be too. The historical evolution of our beliefs on this subject and the speculation of how things could develop in the future represent a fascinating topic of class discussion. Changing interpretations of the structure of the Universe over human history have overturned established social structures and how we perceive ourselves in the context of the Earth and the Universe. The discovery of extraterrestrial life will have an equal if not greater impact on society.

May be the most significant implications on the question of “our place in the Universe” and the search of extraterrestrial life is changing our perception of ourselves: not as citizens of certain nations, member of certain races, or adherents of certain regions, but as common inhabitants of planet Earth. The education value of this concept goes far beyond any humanities or social science course can deliver.

1.4.4 Current state of science education

In most universities today, science is taught by discipline. Students enroll in programs or majors of a specific discipline such as physics, chemistry, or biology. Students often perceive these subjects as segregated and not related to each other. In research-intensive universities, emphasis is placed on preparing the students for graduate work, earning a Ph.D. degree, and becoming the next generation of researchers.

The emphasis on specialty training is particularly strong in Russia, Asia (China, Japan, Korea) and in certain countries in Europe. Students and young researchers are encouraged to dig deeper into increasingly narrower subject areas. In order to give students a broader education, many North American universities have out-of-major requirements to supplement the major courses. For example, it is common to have distribution requirements for undergraduate science students to take courses in humanities and social sciences, such as psychology, economics, or history; and for non-science majors to take science courses such as physics or biology. However, these courses are often introductory courses in these disciplines and are not designed specifically to be relevant to the out-of-major students.

An alternative approach to university education is to adopt a whole-person training philosophy where the emphasis is to develop students as intellectual beings capable of analyzing the increasing complex problems of the modern world. The goal is not so much to impart factual knowledge of a particular discipline, but to train students to be aware, to observe, to analyze, and to produce solutions to unfamiliar problems.

1.4.5 A new approach of teaching science

Although the knowledge content of astrobiology is interesting in its own right, I am more keen to use the teaching of astrobiology as a tool to develop students' intellectual abilities. In our education system, science courses often focus on the description of current models. Courses in biology and chemistry are commonly laden with facts, and courses in mathematics and physics are filled with abstract derivations. It is not to say that these are not useful, but it may have missed an important element of science education. Most science courses inform students on our current interpretations on how things are, with little attention paid to how scientists came to the present points of view. In fact, science is about the process of rational thinking and creativity. What we consider to be the truth is constantly evolving and has certainly changed greatly over the history of humankind. The essence of science is not so much about the current view of our world, but how we changed from one set of views to another. Our goal of science education should not be about the outcome but the process (Preface, Kwok 2017). We should try to help students develop the ability to observe, to deduce patterns, and to hypothesize on the origin of these patterns. Understanding the process of scientific thinking benefits students in all areas of study, not just science students.

This approach of teaching was used by me to teach a common core course at the University of Hong Kong between 2010 and 2018 to about 100 students per year drawn from all faculties of the university. The content of the course is designed to inform the students that our world views are the result of observations, pattern recognition, logical deductions, predictions and further experimentation. This process is applicable not only to science but in our everyday lives. By going through the historical examples discussed in the course, students learn to be suspicious of authority, be less willing to conform to current way of thinking, and be bolder to explore new ideas. These potential effects on students have far greater impact on their lives than any knowledge content that science courses may impart on them.

During my tenure as President of the Astrobiology Commission of the International Astronomical Union, I tried to promote this approach of science education and use astrobiology as a tool to develop new ways of science teaching, in particular in developing countries. As traditions are strong, change is not easy. The rapid development of the field of astrobiology, however, offers a better opportunity as a vehicle for education reform than other more established or entrenched disciplines of science. Being at the wide open frontier of interdisciplinary science, astrobiology can make a stronger case that the next generation of scientists be educated differently.

Acknowledgements

My interest in astrobiology began when I first read the book “Intelligent life in the Universe” by Shklovksii and Sagan in 1973. Much of the content of the book is still relevant today.

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