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Viewpoint

# Astrobiology—a new opportunity for interdisciplinary thinking

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**Abstract**

During the past decade new questions in science have emerged that require broad inter-disciplinary approaches. 'Do asteroids and comets cause extinctions?' and 'Was there, or is there, life on Mars?' are just two examples of questions that cut across planetary or astronomical sciences and biological sciences. The re-emergent science of 'astrobiology' represents a new synthesis of inter-disciplinary thinking that in many respects bears similarities to what in the 18th and 19th century would have been called 'Natural Sciences'. But new astrobiology offers the scientific community, including the space community, two important possibilities. First, an opportunity to galvanize diverse scientific disciplines together to answer some fundamental questions on the relationship between life and the cosmic environment and, second, a chance to create a new environment conducive to interdisciplinary thinking. This is in contrast to the general trend that occurred during the 20th century towards increasing specialization in the sciences. During the 21st century astrobiology has the potential to open rich and productive seams of research.


## 1. Introduction

Astrobiology was first used as term in 1953 in the Soviet Union to describe a science focused on the search for life on other worlds [1]. But during the 1990s it saw a re-emergence. Initially it became the vanguard of a new NASA effort, primarily to respond to newly focused interest in the possibility of life on Mars and the Jovian moon, Europa, but also to provide a framework for answering many other questions that had come to the forefront of space and biological sciences. After this re-emergence, quite rapidly the science took on international dimensions with the formation of new networks and institutions and dedicated journals.

The new synthesis of astrobiology has taken on a meaning much wider than its original definition. Definitions of the new science vary, but it is generally seen to be a science concerned with 'the origin and evolution of life in the Universe' or derivations of this theme [2], which as the reader can appreciate, is a broad definition. In an earlier publication, I examined the histories of the terms 'astrobiology' and 'exobiology' and the confusion that existed in the definitions of these similar terms [3]. Exobiology was coined in 1960 by Nobel Laureate Joshua Lederberg specifically to mean the study of life off the Earth [4]. Although the definition of the new re-emergent 'astrobiology' was initially cloudy, partly on account of its breadth, from this cloudiness have emerged new opportunities to mould inter-disciplinary questions that link planetary and astronomical sciences and many fields in the biological sciences. Some of these questions, such as that of life on other planets, remain profoundly interesting to scientists and the public alike.

Astrobiology is similar to what in the 19th Century would have been called 'natural sciences'. 'Natural science' has no real definition other than perhaps 'the study of the natural world', but it continues today as an undergraduate course at the Universities of Oxford and Cambridge. Many institutes and departments around the world refer to themselves as Departments or Faculties of Natural Sciences. This is precisely because it has a broad interdisciplinary scope that offers not just a good educational benchmark for undergraduates, but also encourages a fertile cross-fertilization of ideas from one field to another. Natural sciences covers physics, biology, biochemistry, astronomy, mathematics, history of science and other fields.

In this paper I suggest that astrobiology can be seen as a timely re-emergence and re-invigoration of 'natural sciences', but with a focus on more contemporary questions that require inter-disciplinary thinking. These questions include the search for life on other worlds, the

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opportunities for human life off the Earth, such as human Mars missions, and the effects of the astronomical environment on the evolution of life on Earth. In a previous publication the confusion that can exist in the re-emergence of new fields and the caution that must be exercised when fields become strongly linked to media interest was discussed [2]. Here I describe the way in which astrobiology offers a new, important and fertile ground for inter-disciplinary thinking.

## 2. Astrobiology—its questions

The questions of astrobiology are well enunciated by NASA's efforts to establish an astrobiology roadmap that sets out a series of key scientific goals that themselves sit under a series of scientific questions [5]. Of course, astrobiology, 'the study of life in the Universe' could encompass almost any series of questions that relate to the origin and evolution of life, but the roadmap illustrates the types of questions that astrobiology asks.

The first question is how life begins and develops. There are four goals that can be elaborated within this question. They are to find out how life arose on Earth, what principles govern the organization of simple organic molecules into living systems, how life evolves on the molecular, organism and ecosystem levels and how the terrestrial biosphere has co-evolved with the Earth. Each one of these goals develops a greater level of complexity from the one before it, but the focus of all of them concerns the way in which life originated and the way in which its manifestation is influenced by the nature of the planet on which it evolves. Within these goals is a diversity of questions. For example, the goal to study the organization of simple organic molecules into life might involve the study of the formation of prebiotic organic molecules, which might be formed, for instance, on interstellar ices. To examine this question requires an understanding of the physical environment of interstellar space and knowledge of the chemistry of the environments in which one supposes these reactions are occurring. One also needs to know about early biochemistry and the supposed nature of early protocells to be able to understand which organic reactions may be important. This is just one example of how many fields of research can be brought to bear upon the question of how life originated.

The final goal in this question, concerning the co-evolution of the terrestrial biosphere with the Earth, might examine the role of asteroid and comet impact events in disrupting ecosystems on Earth and it might examine the way in which they recover. To address this area of research requires a knowledge of the frequency of impact events (itself deduced from direct astronomical observations of near-Earth objects or from studies of cratering rates on other solid planetary surfaces), a knowledge of the biological effects of impact events and a knowledge of the way in which ecosystems recover from localized ecological disturbance, yet another example of why an inter-disciplinary framework for research is required.

The second question established by NASA asked whether there is life elsewhere. From the public point of view this is perhaps the most interesting and the best known question, although from the scientific point of view it is currently perhaps the hardest to test. Like the first question, it too comes with four goals, which are: to determine the limits for life as an analog for other worlds, to determine what makes a planet habitable, to determine how to recognize a signature for life on other worlds (this could be physical biomarkers on, say, Mars or spectroscopic indicators of life in the atmospheres of extrasolar planets) and finally, of course, to determine whether there is actually life on other bodies in our Solar System. Each of these goals is inter-disciplinary. For example, to understand the limits of life at high temperatures requires a knowledge of the highest temperature habitats to be found on Earth (environmental sciences). It requires knowledge of the physiology of organisms found in those habitats (microbiology), their relationships to other organisms (molecular biology), how these environments sustain these organisms (chemistry) and the way in which molecules behave at such high temperatures (physics and biophysics).

The third and final question identified in the astrobiology roadmap is to determine what the future of life is on Earth and beyond. Two broad goals are recognized within this question. First, determining how ecosystems respond to environmental change on time-scales relevant to human life on Earth and, second, understanding the response of organisms to conditions in space or on other planets. This last goal covers the controversial discussion of the transfer of life between planets (panspermia) to the less controversial transfer of human life to other planets. This last objective could be accomplished during human piloted missions back to the Moon, to Mars or even to other Solar System bodies, such as comets.

## 3. Why astrobiology now?

Inter-disciplinary thinking is not new. What is new is the notion of establishing a field of science that seeks to create more inter-disciplinary links rather than moving towards specialization. During the 20th Century science had a tendency to specialize. The century saw the emergence of nanotechnology, molecular biology, glycobiology, high energy particle physics, nuclear physics and other disciplines of science that were a direct offspring from less specialized branches of science.

Many of these new branches had their own departments in universities and other institutions. The prevailing philosophy behind this trend seems to have been that as knowledge increases, so it is necessary to compartmentalize, not just to help order the new knowledge, but also because it would be impossible for any single individual to know everything about many subjects.

Astrobiology emerged from the recognition that some questions, and particularly those that relate to the evolution of life and its connection with space sciences, require interdisciplinary thinking. It is not possible to identify any point in history at which this realization occurred, but it seems to have occurred on many fronts. For example, the link between the Cretaceous-Tertiary extinctions and an impact event re-opened an invigorated debate about the role of extraterrestrial agents in extinctions during the 1980s. To address this new emergence of catastrophism required a knowledge of space sciences as well as evolutionary biology. In the 1990s few of the people who studied cratering rates or the atmospheric effects of asteroid and comet impacts knew much about evolutionary biology and few evolutionary biologists knew much about the mechanics of impact events. Astrobiology has provided the environment to change this.

It had long been recognized that in order to seek life on Mars, one must first know where the most likely place to look is—what are the most likely habitats and micro-habitats?. However, to answer this question successfully requires that you know where life survives in extreme environments on Earth. Few planetary scientists had a grasp of microbiology in extreme environments in the 1990s and few microbiologists had a grasp of the planetary geology of Mars. An interdisciplinary field that encouraged these two groups of people to talk to one another would clearly be productive for answering the question of life on Mars.

Each of the goals listed in the previous section can similarly be identified as possessing the requirement for an interdisciplinary approach. Astrobiology has provided a formal framework, and it is hoped, a funding framework, for addressing questions that have, until now, been limited by their study to single disciplines. Thus, it should be clear why the time has arisen for a science that is less specialized and focuses its attention on interdisciplinary thinking.

As I have suggested, astrobiology bears many similarities to 'natural sciences'. The meaning of this term is quite nebulous, but it was used in the 18th and 19th centuries for any subject or scientific question that addressed aspects of the natural order of things, from zoology to astronomy to mathematics. In a world where disciplines such as physics and biology were not obviously disconnected and society was beginning to unravel the patterns to be found in nature, natural sciences provided a convenient mechanism for scientists to begin to examine such questions as 'what is the nature of light?' and 'what are stars made from?'. Many of the new questions being asked and many others besides had no obvious disciplinary alliance. Without a prior knowledge it is not clear whether the two questions above might involve physics, chemistry or astronomy or a combination of them in different measure.

In some sense astrobiology is a similar retreat into an inter-disciplinary milieu in the face of questions that perplex us. Is the search for life on Mars about biology, planetary geology or physics for example, or about all of these and in what proportions?. By creating a field that allows scientists of many disciplines to interact, one is not compelled to provide an answer to this question. What becomes important is that the intellectual environment is provided to allow these interactions to occur, so that as much biology, planetary geology or physics can be drawn into the question as appropriate at any given time.

## 4. The future of astrobiology

The future of astrobiology, like natural sciences, has no defined end point. It ends when the scientific community decides that it no longer offers an intellectual environment of relevance for answering the questions at hand. This might seem cynical, but it is really quite true of any scientific discipline. A 'discipline' is an artificial construction. There are few scientific questions that are so tightly constrained that they can be conveniently boxed solely into one area of study. Biochemistry will end when there is no biochemistry to do any longer—when everything about chemical reactions in biological systems is known. On this basis biochemistry has quite a long history ahead of it.

Astrobiology is slightly different because it comes with a set of expectations. Few members of the public actually harbour any serious expectations from biochemistry, which, if not met, will make them lose confidence in the science. But astrobiology has come along with the expectation of finding life on another planet—perhaps its most potent question. It is plausible that if, in 20 years time, we are no closer to answering this question, then astrobiology will loose favour. Indeed, in a previous publication I focused quite exclusively on the problems of declaring new fields of science when they can be quite heavily built on public and media interest [3]. I still think this is an unresolved problem in the emergence of new fields of scientific activity, particularly in societies where marketing and media interest are so prevalent in the political support for science.

Astrobiology has a potentially long history if not too much focus is placed on answering the question of life on other planets, a point that has been made before [6].

The remit of its questions, summarized above, is broad enough that it can act as the inter-disciplinary vehicle for many important insights in the coming decades and centuries.

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