International Journal of Astrobiology 8 (1): 51–61 (2009). Printed in the United Kingdom
doi:10.1017/S1473550408004370

Aliens are us. An innovative course in astrobiology

Carlos F. Oliveira and James P. Barufaldi

Center for Science and Mathematics Education, The University of Texas at Austin, Austin, TX, USA
e-mail: carlos.oliveira@mail.utexas.edu

Abstract: We live in a scientific world; paradoxically, the scientific literacy of the population is minimal at best. Science is an ongoing process, a human endeavour; paradoxically, students tend to believe that science is a finished enterprise. Many non-science major students are not motivated in science classes; paradoxically, there is a public fascination with the possibility of life in the Universe, which is nowadays a scientific endeavour. An astrobiology course was developed at the Center for Science and Mathematics Education at The University of Texas at Austin to address these paradoxes and includes the following objectives: (a) to improve scientific literacy; (b) to demonstrate that science is a work in progress; (c) to enhance the inherent interdisciplinary aspect of science; (d) to demonstrate that science is embedded in society and relates with several social sciences; (e) to improve the content knowledge about the nature of science; (f) to illustrate how engaging learning science can be; and (g) to draw from the intrinsic motivation already incorporated in the general population. The course has been offered, taught and revised for the past three years. The informal course student feedback has been very positive and encouraging. The purpose of this paper is to provide a general overview of the course. In addition, the course's background, content, themes and mode of delivery are outlined, discussed and analysed in this paper. This paper subscribes to an educational philosophy that focuses on the multidisciplinary nature of science and includes critical thinking-based teaching strategies using the dynamic discipline of astrobiology.

Received 23 September 2008, accepted 11 November 2008, first published online 3 February 2009

Key words: astrobiology, course, college, non-science majors, critical thinking.

Introduction

In order to increase students' scientific literacy (Oliver & Fergusson 2007), critical thinking and knowledge of the nature of science, a course was created at the University of Texas at Austin. The hook of the course is the increasingly very popular, appealing, motivating and exciting subject of extraterrestrial life (Kaufman 2008; Oliveira 2008).

Astrobiology, as defined by the NASA Astrobiology Institute, is:

> 'The scientific study of the living Universe: its past, present, and future. It starts with investigating life on Earth, the only place where life is known to exist, and extends into the farthest reaches of the cosmos. It ranges in time from the Big Bang and continues on into the future'' (NAI 2008).

It studies the origins, evolution and distribution of life in the Universe; thus, it studies life on Earth, and searches for life beyond our planet. Astrobiology covers many questions, of which the best known is: 'Are we alone in the Universe?' (Oliveira 2008).

The course focuses on interdisciplinary issues related to the idea of extraterrestrial life. It covers a wide range of topics, drawing on astronomy (the instructor's background, and thus the major science of the course), physics, chemistry, biology, anthropology, geology, psychology, sociology, history and the effects of science on society and *vice versa*. This integration of several sciences (Lunine 2005), allows the students to experience science in a holistic manner and to attain knowledge from different sciences (Oliveira 2008). The knowledge of different sciences is very important for a democracy and decision-making in an informed society, as noted by Sagan (1997) and Feynman (1999) (see also Davidson (1999)). This integration already exists in research, since 'many astrobiologists seek more than collaboration – they are pursuing true cross-disciplinary research that is oblivious of disciplinary boundaries' (Brazelton & Sullivan 2008), thus the goal is to embrace this philosophy within astrobiology education. The transcendent science of astrobiology (Staley 2003) brings synergies to education as it does in other areas of human life (Sapp *et al*. 2002), seeing astrobiology in a more holistic way, more than just the sum of its science parts.

The course is provided primarily to non-science majors. Although many of these students will not be science researchers, they will be the decision makers of tomorrow, thus it is very important that they understand the current scientific world in which we live (Hurd 1998; Kolso 2001).

Non-science majors need a functional level of scientific knowledge (Shamos 1995), to like science, to have fun with science, to be aware of the nature of science, to understand the relationship between science and society, to erase misconceptions about science and to know how to think rationally. Developing critical thinking is the major goal to be achieved by considering alien life from scientific and social perspectives. These socio-scientific issues are being urged by science education researchers to be introduced into classrooms (Hanegan *et al.* 2008).

The astrobiology course was developed at the Center for Science and Mathematics Education (CSME) at The University of Texas at Austin. The CSME provides a wide range of courses in the sciences including Earth science, life science and conceptual physical science. The astrobiology course is the first interdisciplinary offering by the CSME. At least one of these courses is offered each academic semester. The decision to offer these courses depends on the schedule of available instructors and the interest of potential students. Many students enrol in these courses as an elective. These courses are designed and offered to provide a better understanding of the nature of science, to improve scientific knowledge and to promote critical thinking.

This astrobiology course was first taught three years ago, and has been revised each year to reflect student input, new scientific information and self-reflective examination by the instructor of the course.

Background

In 2004, Abrams & Morrison (2004) surveyed 42 courses on 'life in the universe'. They found that the courses mainly included the following subjects (Morrison 2002; Brake *et al.* 2006):

- History of the Universe;
- Formation and History of the Earth;
- Nature of Life;
- Evolution of Life;
- Extraterrestrial Life;
- Life in Extreme Environments;
- Life in Our Solar System (Mars and Europa);
- Aliens, Science Fiction and the Search for Extraterrestrial Intelligence (SETI);
- The Future of Humankind in the Universe.

An informal survey conducted in 2006 revealed that most 'extraterrestrial courses' were pure science courses, where the Drake Equation is used as an organizational tool in order to teach 'introduction to biology', 'introduction to chemistry', 'introduction to astronomy' courses; only a few of the courses concentrated on the history of the idea of extraterrestrial life; and courses rarely debated the science fiction imagination and the UFO myth. Even when these topics appeared in the syllabus, they were placed at the end of the course leaving no time to cover them in depth.

It was decided that a 'perfect course' would be one that tried to incorporate all of these subjects, under the umbrella of critical thinking.

Also, the subject of astrobiology is the perfect hook to attract people to study science, the ongoing scientific process, the nature of science and the interdisciplinary aspect of science, while erasing some science misconceptions on the way (Oliveira 2008).

Understanding the nature of science is very important to science literacy (AAAS 1989; Matthews 1994; McComas & Olson 1998; NRC 1996; NSTA 2003). McComas *et al.* (1998) argue that knowledge of how science works enhances students' understanding of science as a human endeavour, increases interest in science and science classes, improves student learning of science content and promotes better social decision-making (Olson *et al.* 2008). As Driver *et al.* (1996) emphasize that 'understanding of the nature of science is necessary if people are to make sense of the science and manage the technological objects and processes they encounter in everyday life … [and] make sense of socio-scientific issues and participate in the decision-making process'. Students should learn to understand the purpose of science, the general assumptions underlying scientific knowledge, and the interplay of science, culture and society influencing the development of scientific knowledge (Lederman *et al.* 2002; Kremer *et al.* 2008). Shamos (1995) even claims that understanding the nature of science is the key knowledge that citizens use when assessing public issues involving science and technology (Olson *et al.* 2008). Thus, it is very important that the nature of science is embedded into a science course for non-science majors.

In addition, people already believe and are fascinated by alien life, thus students will be inherently motivated, curious and engaged in this course (Slater 2006; Sullivan & Morrison 2008).

On top of all this, our course ingrains the four principles within the NASA Astrobiology Roadmap (Des Marais *et al.* 2003): integrating scientific principles, planetary protection, astrobiology and society, and future generations (Morrison 2001; Brake & Griffiths 2004b).

Syllabus

The course has four sections. At the end of each section, there is an exam to evaluate student's knowledge of the material covered.

The four main themes of this upper-division astrobiology course are: the History of the idea of Extraterrestrial Life, the Drake Equation, Scientific Speculation and Science Fiction.

The course starts with a historical perspective to understand how the idea of extraterrestrial life originated and evolved. Then, a series of factors, important in determining whether extraterrestrial life is possible, are examined. Next, the course focuses on the 'search for aliens' and 'trying to contact them', and the question of whether Earth has been visited by extraterrestrials is approached critically. Finally, the course discusses the importance of science fiction in society and its impact on the current extraterrestrial life framework.

https://doi.org/10.1017/S1473550408004370 Published online by Cambridge University Press

The first section is about History. The lectures have the following themes: Ancient Concepts of Plurality; The Copernican Revolution; The Sidereal Revolution; and Canals on Mars.

The second section is about Science. The lectures have the titles: Drake Equation; Star Formation; Extrasolar Planets and Habitable Planets; Origin and Evolution of Life on Earth; Origin of Intelligence; Human Evolution; Cultural Evolution; Lifetime of Communicable Civilizations; and Evaluating the Drake Equation.

The third section allows for Scientific Speculation, under the subjects: Fermi Paradox; Life in our Solar System; SETI program; Interstellar Travel; and UFOs.

The fourth section is devoted to Science Fiction: What is Science Fiction; Themes and Messages in Science Fiction; History of Science Fiction; the movie and the novel *Contact*; the novel *Hitchhiker's Guide to the Galaxy*; the novel *Childhood's End*; the novel *Black Cloud*; the *Star Wars* movies; the *Star Trek* series; and many other Current Science Fiction works that use Extraterrestrials.

Assessment

It was decided that a multiple criteria grading system is the fairest and least stressful for these students (Rubadeau & Rubadeau 1983). It allows students to work mainly on their own, having control of their progress and to think about the topics instead of memorizing facts (Prather & Slater 2002). Thus, throughout the course, students are required to complete four exams with take-home essays, one essay reviewing a science fiction novel, one project integrating astrobiology with their major area of study, one presentation, an oral examination and 10 homework assignments where students have to critically discuss different astrobiology issues. Self-reflecting essays and critical thinking are major characteristics of the course. In addition, students must also attend classes and actively participate in them. An ongoing, continuous, gradual assessment of the students is conducted.

Methods of delivery

A student-centred delivery method is applied. The classes are delivered in an open-forum format, with inquiry, that encourages discussion, interactivity and critical thinking on the students' part. The instructor acts mainly as a guide. The format allows critical thinking and permits scientific speculation, in a more informal environment.

At the beginning of each class, 15 minutes is devoted to discussing current news on the subject of astrobiology. This allows students to understand science as an ongoing process, erasing some of its misconceptions (Oliveira 2008). Most of the classes include game-like activities that make the class a fun learning environment.

At times, students gather informally to view movies and documentaries. These opportunities take the learning to a multimedia level usually not available during class time. The DVDs viewed include: the movie *Contact* (1997), the movie *K-PAX* (2001), the documentary *Fantastic Voyage: Evolution of Science Fiction* (2002), the documentary *How Star Trek Changed the World* (2005), the documentary *Star Wars: the Legacy Revealed* (2007), the documentary *Evolution of Life* (the second part of Nova's *Origins* four-part 2004 documentary), the documentary *Alien Planet* (2005) and the documentary *Last Days on Earth* (2006).

History

The course begins with the History section. The goal of the first part of the course is to provide a historical and cultural context on the idea of extraterrestrial life. The objective is to make students realize the differences between scientific arguments and other arguments from other areas of society. One of the main goals is that students obtain a better understanding of science. It is expected that, by performing a critical analysis of the past, students will be able to make parallels with the present and thus have a better understanding of the world that surrounds us. Another main goal is that students understand that throughout history, the arguments were not really about aliens, but about what humans wanted.

One of the goals of this section, as well as other sections, is for students to understand the nature of science: science evolves as a tentative, dynamic, ongoing process, science is empirical, science is subjective, science is partly creative and imaginative human endeavour, science is socially and culturally embedded (Lederman *et al.* 2002). In this section of the course, students study more than 100 individuals throughout history.

The mandatory reading for this section is Michael J. Crowe's 1986 book *The Extraterrestrial Debate 1750–1900*.

Arguably, the ideology regarding intelligent beings outside Earth started several millennia ago with creation myths (Dick 1998). It showed god-like all-powerful extraterrestrial beings, who supposedly created life on Earth and who continued thereafter to be very interested in Earth and on influencing the daily life of humans. These humanoid gods were in all aspects like humans, with the same forms, characteristics, psychology, attitudes, behaviours, etc., except that they had more power (Grinspoon 2003). Humans created these extraterrestrial gods in order to explain the gaps in understanding the world.

In the 4th century BC, Plato and Aristotle adopted this geocentric cosmos (Koestler 1959) where a God ('Prime Mover') would be constantly looking at us from above. With Earth at the centre of the Universe, humans are the great beneficiaries. This orthodox view is all about humans; humans wanted to be the most important and interesting piece of the Universe, and thus they put themselves at the centre, even if only psychologically (Brake 2006).

In 1277, theologians such as the bishop of Paris, Etienne Tempier, decided to condemn those who would say that God could only make one world (Dick 1982; Hennessey 1999), because that would be limiting God's power. From that time on, other worlds and their possible life became the subject of debates.

https://doi.org/10.1017/S1473550408004370 Published online by Cambridge University Press

In the 15th century, Nicholas of Cusa, a Cardinal of the Catholic Church, was among the first to speak about extraterrestrial life; although many had already considered a plurality of worlds (Sagan and Shklovskii 1966). He thought that extraterrestrial inhabitants are rational beings of a different rank than the men from Earth; for instance, while on Earth humans are 'gross and material' (Crowe 1986), the inhabitants of the Sun are bright, enlightened and spiritual. One may think that this is a very anthropocentric view, however that was not the idea of Cardinal Nicholas. For him, Man was the measure of all beings in the Universe. Man was the 'pinnacle of Creation' (Crowe 1986), and thus all the other beings only existed in relation to humans. Not only that, but aliens basically had the same characteristics as humans, just more intensified in certain aspects. This reinforced the message that by and large the Cardinal saw the aliens as another version of humans.

The Renaissance brought new lands on Earth, new people on Earth, new science, new technologies and new ideas concerning the Universe (Ferris 1989). In terms of extraterrestrial beings, the Renaissance brought an apparent increase of diversity among them.

There was also a shift in the arguments. The main arguments are now analogy ('if Earth is a planet, then planets are Earths') (Dick 1996) and the religious argument (Christ became incarnated on Earth, thus Earth is still special).

The face of pluralism in this period is Giordano Bruno. He believed in many Suns and many inhabited worlds. Like the Dominican monk Tommaso Campanella, the Reverend John Wilkins, and many others, Bruno used analogy and argued that 'a plurality of mankinds' (Crowe 1986) enhanced the glory of God. For him, the inhabitants of other celestial bodies were beings like ourselves.

In the 17th century, Bernard le Bovier de Fontenelle had a tremendous success with his 1686 *Entretiens sur la pluralité des mondes* (de Fontenelle 1990). In this work, he populated everything except stars. The arguments that he used were the same those used earlier, analogy and religion. Although he considered himself anti-anthropocentric due to the diversity of aliens in his work, the truth is that the characteristics of his aliens are just exaggerated versions of humans, for example: some aliens would use voice, others would use sign language; some aliens would have a six sense, others would lack some sense; some aliens would be black, while others were white; some aliens loved peace, others war; some lived in groups and others in isolation; some eat meat, while others only eat vegetables; some were dwarfs and others giants, etc. Earth was a miniature Solar System where all of the features were concentrated. Thus, in fact, his pluralism was a mask to congratulate humans on Earth. His incredible influential work made new assumptions about the prominent status of Man; Man is the measure of all beings and all of the extraterrestrial beings are basically human.

About the same period, the famous Christiaan Huygens criticized the wild speculations of Fontenelle, while making the assumption that aliens would be like humans: similar bodies, same senses, same moral, same attitudes. In essence, he also celebrates the greatness of mankind by stating that aliens are humans.

During this period, with a few exceptions (namely Cyrano de Bergerac), many other authors populated the planets with aliens that had human characteristics. On the whole, aliens were humans.

With the Enlightenment, new authors appeared, but the underlying premise continued the same. Thomas Wright of Durham and Immanuel Kant believed in a ranking of beings, with a gradation of many levels of perfection: for Wright the most virtuous rational beings are closer to the Sun, while Kant had the opposite hierarchy. Like Cardinal Nicholas of Cusa before them, they believed that Man was the measure of all beings in the Universe: aliens were just another version of humans.

The Reverend Thomas Dick, like Chalmers and others, used pluralism in his sermons to excite and motivate people. His idea about only one religion in the Universe mirrors his idea that on Earth should be only one religion; thus mankind had the 'right religion', which should spread throughout the Universe. Moreover, in 1837, he made a cosmic population census, calculating almost 22 trillion intelligent beings in the Universe. His calculations were based on Earth and how humans get together using the population density of England. Essentially, he calculated how many aliens there would be if all aliens were humans and living like humans.

1835 was the year of the Moon hoax. Richard Locke, a New York journalist, made up stories about supposedly discoveries of living plants, animals and rational beings on the Moon. All of these beings were, at heart, the same types of beings that we see on Earth. Even the rational beings, called men-bat, were fundamentally humans with huge bat wings. The readers of the newspaper did not understand the satire, and totally bought that the aliens were basically humans.

A few years later there was a feud between William Whewell and David Brewster. While coming from opposite directions, Whewell rejected pluralism while Brewster embraced it, they both had the motif of not wanting humanity to lose a central significance in the cosmic plan: Whewell wanted God just for humans with no other beings to be taken care by God, while Brewster argued that since Christ redeemed the sins on Earth then Earth and humans were the most important things in the Universe. These religious arguments are very common throughout history, and the psychological reasons behind them are also usually the same: several dozens of people throughout history argued the same way as Whewell and Brewster. Man has a vital place in the Universe. It is all about us, all about humans. The aliens are just sidekicks in a stage clearly made for humans.

By the middle of the 19th century, arguably the best popularizer of all, Camille Flammarion (Guthke 1990), who still greatly influenced the 20th century attitudes to the extraterrestrial idea (Dick 1996), proposed a diversity of life in the Universe: some beings would have additional senses, others would have other sexes, others could be immortal, etc. Although in his idea there was no justification for aliens to look like humans, he still thought that all evolution, on

https://doi.org/10.1017/S1473550408004370 Published online by Cambridge University Press

any planet, always leads to rational creatures. Thus, for him, although aliens could be diverse, with different forms and characteristics, the fact is that he still thought that the end result of evolution, the pinnacle of Creation, should still be rational beings like humans. All evolution in any planet should lead to rational-alike human beings. Man is still the measure for all beings. It is still all about humans.

Until the 20th century, pluralism was defended, without observational evidence, and based on faulty, non-scientific arguments, such as: Analogy, Religion, Principle of Plenitude, Principle of Mediocrity, Principle of Uniformity, Wrong Interpretations of Observations, Wild speculations, Probabilities, Personal wishes, etc. All of these arguments are based on humans, their wishes, their characteristics. All of these arguments were about us. Although under the extraterrestrial disguise, these arguments expressed only the psychology, science, reasoning, faith and culture of humans.

At the turn of the century, the battle for the planet of war started. Giovanni Schiaparelli, in 1877, mapped the surface of Mars, with several *canali*: in Italian, it means natural water channels. In USA, it was wrongly translated as canals, artificially constructed paths of water. This incorrect translation led to euphoria in the general population and in the astronomical community, with Flammarion and Lowell at the top of the believers, about an advanced Martian civilization who had built a planetary irrigation system with a complex and highly sophisticated system of canals. These canals were just an optical illusion, fabricated by the human mind. Moreover, this idea of canals being made by an advanced civilization mirrors the human civilization of the time: it was the era of the canals on Earth: Panama, Dortmund, Manchester, including the famous Suez Canal, a modern wonder of the world, opened to navigation in 1869. It was again all about humans. Astronomers were projecting human society onto planet Mars. About this same time, Flammarion proposed that we should communicate with Martians using the telegraph, exactly for the same reason: since we were using the telegraph, then aliens must be using it too. Thus, humans are still the measure of all things.

Overall, throughout history, it is clear that the discussion about aliens does not bring anything new (Hennessey 1999) and is in reality all about humans. Mostly, the big questions are about Man's place in the universe (Michaud 2007) and Man's place at the eyes of God. Whatever the opinion, the underlying motif was to keep Man as the pinnacle of creation. Humans project their culture, expectations, attitudes and characteristics into aliens. The history of the idea of extraterrestrial life, tells us more about ourselves than about extraterrestrials. Aliens are, in fact, us.

Science

The Science section (Lunine 2005) uses the Drake Equation ($N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$) as an organizational tool to teach concepts such as the formation of stars, the chemical basis for life, the methods to detect extra-Solar planets, how many of those planets may be habitable, the origin and evolution of life on Earth, alternative ideas for life on other planets, the evolution of intelligence on Earth, the cultural evolution of the human civilization, speculations on alien technology and language, and speculations about the lifetime of alien civilizations.

The goals of this second part are: to increase scientific knowledge, to know the science behind the idea of extraterrestrial life, to learn scientific concepts, theories and speculations, to study life on Earth and extrapolate about life in the rest of the Universe, to better understand the nature of science, and to become aware that aliens are fundamentally human.

The mandatory reading book for this section of the course is *Life in the Universe* written by Shostak *et al.* (2003).

After a general view of the Drake Equation, the Big Bang Theory is studied, especially in terms of chemistry, in order to learn how the elements necessary for life came to be. Following that, the Solar Nebula theory is analysed with the aim of understanding how the Solar System, stars, discs around stars and planets, formed; the objective is not just to learn how the different chemical elements formed, but also to learn how many stars and planets could there be in the universe, and their characteristics. After understanding the formation of planets, the history of searching for extra-Solar planets, the current seven most important methods to detect them, the characteristics of the more than 300 extra-Solar planets already discovered, and extrapolate about possible future others are studied. Subsequently, Earth, the habitability of the planets, in our Solar System and elsewhere, the life-friendly stars and the habitability of our Galaxy is examined. Finally, how insignificantly tiny our familiar planet Earth is, in space and in time, is explored.

After the astronomical factors of the Drake Equation, biological aspects are considered.

The next big chapter is about the origin and evolution of life (Gilmour & Sephton 2003). In this section the nature of life is discussed: its requirements, its characteristics, its chemical basis, its basic molecules (its properties and constituents, amino acids, bases, sugars, phosphates, proteins, nucleic acids, RNA, DNA, etc.), the Miller–Urey experiment, the different theories for the formation of life, the vital importance of carbon and water, along with other relevant characteristics (Koerner & LeVay 2000). How life evolved on Earth, since its formation until now, with the most important stages being the origin of life, the origin of oxygen, the development of multicellular life and the Cambrian Explosion, is examined. Subsequently, extremophiles are examined: what they are, where they live, which conditions they need and how can we extrapolate the knowledge about them to other planets and which planets (Koerner & LeVay 2000).

Although the scientific details of the subject are provided and discussed, the goal of this chapter, like all of the other chapters, is to critically analyse the big picture. Since students are non-science majors and thus will not work in this area, what is important for them to remember is not the 'boring' scientific details that they memorize for the test and forget the next day, but the big picture of the science behind it

(Grinspoon 2003). With this in mind, a lot of time is spent discussing and analysing Carl Sagan's Cosmic Calendar (Sagan 1986), and trying to draw conclusions from it. For instance, students are expected to realize that the evolution of life on Earth shows that: life started very early after the formation of Earth; most of the time, life was bacterial, unicellular organisms; the multicellular organisms that we know best appeared relatively recently; and humans even more recently. In terms of extremophiles, students are expected to recognize that: life is varied, robust, tough and extremely adaptable to hostile conditions; the fact that we find extremophiles on Earth increases the chances of finding life on other planets (Des Marais & Walter 1999); but complex life cannot survive in extreme conditions, since it needs moderate and stable conditions to survive; and intelligent life needs even more stable and moderate conditions. Thus, from both the evolution of life and the existence of extremophiles, students should anticipate that the probability of finding unicellular extraterrestrial organisms is high (Aczel 1998; Darling 2001), while the probability of finding multicellular extraterrestrial organisms is small (Ward & Brownlee 2000), and finally the probability of finding intelligent extraterrestrial organisms is very tiny (Ward & Brownlee 2000). More than memorizing concepts, the goal is to promote critical thinking.

Next, human evolution is discussed, including the evolution of intelligence on Earth. It is observed that most definitions of intelligence reflect our prejudices and bias; again, it is all about us. Nevertheless, some working definitions are examined, we try to quantify intelligence, and students have to come up with their own ranking of species, based on their own definitions. The origins of intelligence and the lack of importance it has on the survival time of the species are discussed. Several studies made with animals on Earth are analysed. The human evolution from Proconsul until Homo Sapiens is critically analysed, along with theories associated with evolution, for example: convergent evolution, parallel evolution, divergent evolution and punctuated equilibrium.

After the biological factors of the Drake Equation, the social and cultural aspects are considered. Here, the concentration on human affairs is even more important. The next factors are almost exclusively about humans.

The next chapter is devoted to cultural evolution, which includes technological and worldview evolution. Studies about the manipulative abilities of other species are examined, including studies about their language. The evolution of information storage in different species is investigated. The technological evolution of humans, from stone tools to the Internet, is observed. Time is spent discussing the benefits and drawbacks of agriculture, analysing some key advances such as oral and written language, and investigating the power of competition in order to evolve. After that, the evolution of the worldview on human societies is studied, including speculation on how other intelligent species may have a different worldview under different planetary conditions, star system conditions and biological conditions.

Finally, the course speculates on the lifetime of communicable civilizations. The Kardashev classification is examined, including a few hypothetical extension levels. The several mass extinctions that occurred on Earth throughout its history are studied and several dozens of factors that may annihilate our technological human civilization are analysed.

By the end of this section, each student has to provide a critical analysis of the Drake Equation as a whole (Michaud 2007) and has to give about 10 arguments for a higher and for a lower number in each of the factors in the Drake Equation. After determining a possible distance to the nearest communicable civilization, students have to calculate the number of two-way communications we could have with those same potential advanced alien civilizations.

It is important that students realize that the current arguments supporting extraterrestrial life have a logic supported by scientific observations; however, in different parts, scientists still use some wishful thinking, and similar faulty arguments also used throughout history (Basalla 2006). It is also important that they recognize that the efforts to look for life out there are based on a reason of 'life as we know it'; we look for aliens who are very similar to life on Earth. Again, this search tells us more about ourselves than about extraterrestrials: it is all about us.

In past years, while grading the final essays for this section, a pattern was noticed; students were very pessimistic about the idea of finding advanced extraterrestrial life. Thus, the next sections exist to give them a balance, to make them imagine different possibilities, to make them speculate, to expand their minds, to make them more optimistic and to make them dream.

Curiously, a similar recommendation, in terms of imagining different possibilities, was given in a report published by the National Research Council (NRC 2007): it urged NASA and NSF to expand their minds and look for 'weird life' (life with an alternative biochemistry, organisms that lack DNA or other molecules found in life as we know it). In addition to encouraging a wider search (not limited just by Earthly ideas), the Committee left a sombre note: when we find extraterrestrial life, we probably will not even recognize it as life.

Scientific speculation

In the third section of the course, different subjects that could be considered scientific speculation are examined (Pickover 1998; Cohen & Stewart 2002). Possibilities are speculated about, although under the limits of science (Feinberg & Shapiro 1980; Grinspoon 2003).

This is an important section since students need to be able to imagine different possibilities; they need to use their imagination, and understand that science can be inspirational and exciting (Oliveira 2008). It is an opportunity to inspire informed citizens (Des Marais *et al*. 2003).

We start by trying to solve the Fermi Paradox (Webb 2002; Michaud 2007). Although 150 possible solutions are considered, only 30 are analysed in detail. Students are encouraged to think about more solutions that are not included in the 150 list and are guided into discussing several of the solutions in their own groups and come up with the explanations for those solutions. Despite some very imaginative solutions, the fact is that it is always our solutions, our reasoning about what intelligent aliens may think and do, our way of thinking projected into extraterrestrial efforts, our interpretation of nature and our science. It is always about us.

The next chapter is about our Solar System. The planets and moons in the Solar System are toured. Their physical characteristics, the photos taken by the probes, the experiments performed on their soil, how well suited they are for 'life as we know it' and the probabilities of water and life on them as well as which type of life might be probable are examined. We look for what we already know, and in doing so we restrict our efforts to 'looking for us'.

Subsequently the SETI program (Tarter 2001; SETI Institute 2008) is discussed. Its history, its projects, its results so far and the reasons for its results (Clark & Clark 1999) are studied. The science behind it, and how it contributed to some of our current technology, is examined. Different strategies for listening and communicating with advanced extraterrestrial civilizations are considered. We observe, experiment and have fun with several signals sent by humans to outer space; including class activities that deal with them. Students also analyse a few mysterious signals received by SETI. The limitations in receiving and deciphering an extraterrestrial signal (Michaud 2007) are investigated, along with a few limitations in the SETI reasoning and in its current technology. The electromagnetic spectrum and the properties of the wave are studied. Studies on human communication with other species on Earth are reviewed, including communication within those species. Finally, the reasoning behind the idea of SETI, its premises, its assumptions, its problems and the similarities/differences between this reasoning and the arguments used throughout human history, which we studied in the first section of the course, are critically analysed. We debate how, for SETI to be successful, aliens need to be 'humans': they need to have the same kind of intelligence, similar reasoning, same curiosity and desires (wanting to communicate), similar level of development (in the end of the 19th century, Flammarion thought that Martians had a similar level of development as humans, using telegraphs), same frequency, comparable radio technologies, equivalent understanding of mathematics, analogous comprehension of messages, etc. Humans are still the measure for all things. An alien civilization needs to be very similar to a human civilization (Grinspoon 2003; Basalla 2006). Extraterrestrials need to be like us.

The following chapter is devoted to Interstellar Travel. Different ideas for exploration probes (Sentinels, Bracewells, Berserkers, etc.), and several current spacecraft projects, such as Orion, Ramjet and Solar Sailing, are analysed. A few possible future projects are considered, such as Generation Starships and Sleeper Ships. After examining the Theory of Relativity, with concepts such as Time Dilation and its Twin Paradox, the realm of science fiction with some speculative ways of travelling through the stars (e.g. warp drive, hyperdrive, wormholes, teleportation, etc.) is approached. Finally, all of these methods are discussed, and a critical analysis of what we can rationally expect in the future is performed. This chapter is totally dedicated to human technology, to humans spreading in outer space, to humans travelling to other planets, to the human colonization of space; this chapter is about us.

The last chapter is devoted to the UFO phenomenon, which is popularly thought as having an extraterrestrial origin (Sagan & Page 1972). This chapter is not just about speculation, but about pseudoscience and the myths in astronomy (Grinspoon 2003), which are also useful in science education (Negrete 2002; Lanza & Negrete 2007). UFOs are defined and their potential Earthly explanations are discussed. The history of the UFO phenomenon from antiquity until now is analysed, with an emphasis on the modern age of UFO sightings (Jackson 1992). The most important UFO cases worldwide are critically analysed. A few modern cases are scrutinized, focusing on several recent videos, examining them from a scientific point of view. This is done along with individual and group activities to help students question these supposed 'evidence' of UFO sightings. The lack of imagination shown by the 'extraterrestrial UFO hypothesis' supporters, who think that alien civilizations probably thousands or millions of years more advanced than us yet have spaceships similar to our current ones, is debated. The psychology behind UFOs, misinterpretations and myth-making throughout history is studied. The most important scientific research studies done on this subject and the most important researchers on this field (Koerner & LeVay 2000) are considered. By the end of this chapter, the most famous alien abduction cases are dissected, and the lives of the self-identified contactees and abductees are inspected. Overall, the belief that UFOs are extraterrestrials is just that: a belief (Grinspoon 2003); it is a religious belief, where God and angels, who are in the sky looking at us, are substituted by aliens (von Däniken 1968; Sitchin 1976; Temple 1976; Davies 1995; Shermer 2000; Grinspoon 2003). It is interesting that, like the gods, the aliens look the same as the people that invented them: white western civilization. It is an argument based on faith; people need to believe (Shermer 1997). This is an argument embedded in our own psychology: we want to believe because aliens make us feel special; just like the religious arguments in the History section, we want somebody up there that puts us in the central place of attention. Although there are many reasons for the UFO phenomenon, all Earth and human based, people prefer to believe in an extraterrestrial reason, against all evidence, because it is psychologically appealing (Grinspoon 2003; Michaud 2007). We live with an ET meme (Brake & Griffiths 2002). Thus, the UFO phenomenon is all about humans. UFOs are us.

Science fiction

Although throughout the entire course science fiction works were often mentioned and discussed (Fraknoi 2003), the last section of the course is devoted solely to this subject. Some of the most important science fiction novels and movies (Rabkin 1983; Pringle 1996; Mann 2001) are critically analysed in detail.

Science fiction exploits scientific and social issues, while applying a lot of imagination. Albert Einstein used to say that imagination is more important than knowledge (Taylor 2002), since it stimulates creativity (TED 2007), which is important to solve problems, to inventing new technologies, to promote discoveries, to promote arts in society, to think about new scientific theories, etc. Thus, this section allows students to go further than just knowledge can take them (Machado 2005).

After defining science fiction, the relationship between science fiction and human society is discussed. The relationship between science fiction and science (Krauss 1995, 1997), and how much they influence each other (Sagan 1979), is examined, with several examples provided. How science fiction inspires people (Brake & Hook 2008) is discussed. Science fiction is interpreted as being a literature of probabilities instead of literature of prophecies (Brake & Griffiths 2004b). How much of science fiction is based on social (and technological) issues is analysed. What aliens in science fiction represent is studied.

The history of science fiction is examined, beginning with the person who is considered the father of science fiction, Lucian of Samosata, and his two fictional voyages to the Moon, written as satires of his own society. Next, Kepler's *Somnium* (1634), where he used analogy, anthropocentric ideas and believed Man was the best creature, is studied (Kepler 2003). Cyrano de Bergerac's *Other Worlds* (1657), two science fiction stories (travelling to the Moon and travelling to the Sun) which were satires of human society and parodies of Christianity, are examined (de Bergerac 1976); in contrast to all other authors, de Bergerac really criticized our anthropocentric view of creation, as well as the social injustices of the 17th century. Voltaire's *Micromegas* (1752), which is a satire of human ego, pride and vanity, is studied (Voltaire 1989); we are so small, and nevertheless we think we own the universe. H. G. Wells' *War of the Worlds* (1898) is examined (Wells 2005); a fictional invasion of the Earth by an advanced Martian civilization at a time when even astronomers thought they existed on Mars (Brake & Hook 2006). It was a metaphor of Great Britain, a social and political criticism of the British Empire, which relied on technology to kill people with no regrets, like machines. It was a satire about imperialism and the vanity of Man. Subsequently, the class listens to the original radio dramatization of this piece, performed by Orson Welles, which led many people to panic.

Arthur C. Clarke's *Childhood's End* (1953) (Clarke 1980), Fred Hoyle's *The Black Cloud* (1957) and James Gunn's *The Listeners* (1972) (Gunn 1972), are all critically analysed.

A very detailed analysis of two novels follows: Carl Sagan's *Contact* (Sagan 1985), and Douglas Adams' *The Hitchhiker's Guide to the Galaxy* (the compilation of five volumes) (Adams 2002). These two novels are in the mandatory reading list of this course.

Several important science fiction movies related with extraterrestrial life are examined. Students have the opportunity to watch, analyse and debate the movies *Contact* (1997) and *K-PAX* (2001). In addition, students may watch some episodes and documentaries about *Star Trek* and *Star Wars*: the documentaries analyse the science and the social messages underlying the episodes/films. Other movies discussing social and scientific issues are available for analysis: *The Day the Earth Stood Still* (1951), *2001 – A Space Odyssey* (1968), *Close Encounters of the Third Kind* (1977), *Superman* (1978), *Invasion of the Body Snatchers* (1978), *Alien* (1979), *ET – The Extraterrestrial* (1982), *The Abyss* (1989), *Stargate* (1994), *Species* (1995), *Independence Day* (1996), *Starship Troopers* (1997), *Men In Black* (1997), *Signs* (2002), etc.; and the series: *X-Files* (1993), *Third Rock from the Sun* (1996) and *Battlestar Galactica* (2004).

The episodes and movies are reviewed, critically analysed from a social point of view, and the messages they meant to convey are scrutinized. The most common messages within science fiction movies are: the Universe is teeming with intelligence life; aliens are very advanced; aliens are very interested in us; aliens have different human characteristics, but humans seem to have them all; humans are constantly praised, and thus aliens would like to be humans, as it is mostly seen in *Star Trek*; what does it mean to be human, by comparing ourselves to non-humans (Rose 1982); aliens are our past gods; science and religion are compatible; we can have a perfect integration of different areas of society; a person's life should be balanced; we should have an harmony between different parts of life, of a person's world; people should follow their dreams; our life and our world is what we make of it; humans should be constantly improving themselves; people should be happy, optimistic and tolerant; knowledge and critical thinking are crucial for a rational mind; the most important aspects in a person's life are family and the significant other; and the most profound discoveries are not in space, but within us.

It is seen that science fiction is not really about extraterrestrial life, but about human society, the culture of the time (Cohen & Stewart 2002); science fiction is a vehicle to make social criticisms and satires about the author's society. Annette Kuhn said:

> 'Science Fiction movies are reflections of social trends and attitudes of the time, mirroring the preoccupations of the historical moment in which the films were made. Films are treated as sociological evidence. Science Fiction films relate to the social order through the meditation of ideologies.' (Kuhn (1990, p. 10))

Essentially, science fiction is a significant instrument of social criticism and comment on human life.

In the Science Fiction section, as in the History section, humans are the pinnacle of Creation; Man is the measure of all beings in the Universe; it's a glorification of human beings; it is all about humans, humans consider themselves the most important species in the Universe.

We define ourselves, by comparing ourselves with others (Sardar and Cubitt 2002); this is seen in all science fiction works that deal with aliens.

Science fiction adds nothing to our knowledge of aliens. It is all about us. Aliens are us.

Student feedback

The feedback so far about the course is anecdotal. Although all students fill anonymous feedback forms, the most comprehensive feedback comes from informal talks with students. As in other similar courses (Brake *et al.* 2006), students seem to better understand the nature of science after the course, and they seem to have a wider scientific content knowledge.

Student evaluations of the astrobiology course, including comments of the students on the student feedback forms, indicate that students perceive classes as 'motivating', 'engaging', 'extremely informative', 'fun', 'very interesting' and 'exciting'. Students believe that 'the course is very well organized', 'taught in a very enthusiastic and passionate way', with 'insightful and useful knowledge', where the 'debate and opposite opinions are appreciated'. The students also 'love the teaching style' used by the instructor of the course. Students report that they complete the course with a feeling that they 'evolved in the knowledge about science', 'understood how incredible science is', 'see science as a never-ending process', 'developed tools to critically approach' different scientific subjects, were able to develop their own opinions about science in general and astrobiology in particular in a more 'robust, comprehensive, and scientific' sense. In addition, they state that the course helps them to 'think outside the norm'. In the words of one of the students, 'I think the class serves as an eye opener, providing a platform for critical analysis of alien life and the possibilities there in'.

The main complaint reported by these students focuses on the amount of content included in the course. They struggle in the beginning, due to being overwhelmed with information. Their perception is that they 'have to work hard' for this course, that the 'course covers too much information' and that they 'expected less scientific content than what is in reality part of the extraterrestrial life subject'. Despite these complaints, in the end, most of them persist, are successful and obtain excellent grades.

Research and formal evaluations are currently being conducted to objectively determine whether the course is fulfilling the objectives, and if students attain gains in critical thinking skills and demonstrate a more sophisticated understanding of the scientific enterprise and the nature of science. Preliminary results are very promising.

Conclusion

An astrobiology course was developed embracing an educational philosophy that promotes the significance of teaching science to non-science majors, endorses the importance of multidisciplinary content analysis, advances the discussion of socio-scientific issues, and encourages the use of critical thinking. The student feedback, preliminary results of research and formal evaluations from this innovative course demonstrate that this course has the potential to significantly contribute to science education in general and astrobiology education in particular.

This strong course has an overall message. While humans are seeking their place in the Universe (Michaud 2007), in their minds they remain the centre of the universe: astronomically, biologically, socially and psychologically.

Aliens are us: humans project onto them their hopes, fears, anxieties, dreams, attitudes, behaviours, goals, role in the universe and on Earth, ways of thinking, anthropomorphic bodies and anthropocentric views. It is all about humans, not aliens. Our thinking about aliens is basically a reflection on ourselves. As David Zindell states in *Neverness* (1989): "We do not see things as they are; we see them as we are" (Zindell (1989, p. 371)).

Humans seek truths outside of themselves to complete inner ones. In a world where minds are looking further out into the Universe than ever before, in the end it is only ourselves that we are interested in. The search is not about aliens, but about ourselves, about the meaning of our lives. The more we study space, the more we learn about ourselves. When we study astrobiology, science fiction, or the UFO phenomenon, we are, in fact, studying ourselves.

References

Abrams, S. & Morrison, D. (2004). Undergraduate Educational Opportunities in Astrobiology. *AbSciCon Conference Proceedings*.

Aczel, A.D. (1998). *Probability 1: The Book that Proves there is Life in Outer Space*. Harcourt, New York.

Adams, D. (2002). *The Ultimate Hitchhiker's Guide to the Galaxy*. Ballantine Books, New York.

AAAS – American Association for the Advancement of Science (1989). *Project 2061: Science for All Americans*. Oxford University Press, New York.

Basalla, G. (2006). *Civilized Life in the Universe: Scientists on Intelligent Extraterrestrials*. Oxford University Press, New York.

Brake, M. (2006). On the plurality of inhabited worlds: a brief history of extraterrestrialism. *Int. J. Astrobiol.* **5(2)**, 99–107.

Brake, M. & Griffiths, M. (2002). SETI, british SF and the ET Meme. *The Science Fiction Foundation* **85**, 14.

Brake, M. & Griffiths, M. (2004a). Broad horizons: SETI, science fiction, and education. *Int. J. Astrobiol.* **3(2)**, 175–181.

Brake, M. & Griffiths, M. (2004b). Science fiction and curriculum innovation. In Norris & Stootman, *Bioastronomy 2002: Life Among the Stars* (*IAU Symposium*, vol. 213), pp. 572–576.

Brake, M., Griffiths, M., Hook, N. & Harris, S. (2006). Alien worlds: astrobiology and public outreach. *Int. J. Astrobiol.* **5(4)**, 319–324.

Brake, M. & Hook, N. (2006). Aliens and time in the machine age. *Int. J. Astrobiol.* **5(4)**, 277–286.

Brake, M. & Hook, N. (2008). Darwin to the double helix: astrobiology in fiction. *Int. J. Astrobiol.* **6(4)**, 273–280.

Brazelton, W.J. & Sullivan, W.T. (2008). Understanding the 19th century origins of discipline formation: lessons for astrobiology? *AbSciCon Conference Proceedings – Poster session*.

Clark, A.J. & Clark, D.H. (1999). *Alien: Can We Make Contact with Extraterrestrial Intelligence?* Fromm International, New York.

Clarke, A.C. (1980). *Childhood's End*. Pan Books, London.

Cohen, J. & Stewart, I. (2002). *What Does a Martian Look Like? The Science of Extraterrestrial Life*. John Wiley & Sons, Hoboken, NJ.

Crowe, M.J. (1986). *The Extraterrestrial Life Debate: 1750–1900*. Dover, New York.

Darling, D. (2001). *Life Everywhere: The Maverick Science of Astrobiology*. Basic Books, New York.

Davidson, K. (1999). *Carl Sagan: A Life*. John Wiley & Sons, New York.

Davies, P. (1995). *Are We Alone? Implications of the Discovery of ET Life*. Penguin, London.

de Bergerac, C. (1976). *Other Worlds: The Comical History of the States and Empires of the Moon and Sun*. New English Library, London.

de Fontenelle, B. (1990). *Conversations on the Plurality of Worlds*. University of California Press, Berkeley, CA.

Des Marais, D.J. *et al*. (2003). The NASA Astrobiology Roadmap. *Astrobiology* **3(2)**, 219–235.

Des Marais, D. & Walter, M. (1999). Astrobiology: exploring the origins, evolution, and distribution of life in the Universe. *Annu. Rev. Ecol. Systematics* **30**, 397–420.

Dick, S.J. (1996). *Biological Universe: The Twentieth-century Extraterrestrial Life Debate and the Limits of Science*. Cambridge University Press, Cambridge.

Dick, S.J. (1998). *Life on Other Worlds: The 20th Century Extraterrestrial Life Debate*. Cambridge University Press, Cambridge.

Dick, S.J. (1982). *Plurality of Worlds: The Origins of the Extraterrestrial Life Debate from Democritus to Kant*. Cambridge University Press, Cambridge.

Driver, R., Leach, J., Millar, R. & Scott, P. (1996). *Young People's Images of Science*. Open University Press, Buckingham.

Feinberg, G. & Shapiro, R. (1980). *Life Beyond Earth: The Intelligent Earthling's Guide to Life in the Universe*. Morrow, New York.

Ferris, T. (1989). *Coming of Age in the Milky Way*. Anchor Books, New York.

Feynman, R.P. (1999). *The Pleasure of Finding Things Out*. Perseus Publishing, Cambridge.

Fraknoi, A. (2003). Teaching astronomy with science fiction: a resource guide. *Astron. Educ. Rev*. **1**(**2**), 112–119.

Gilmour, I. & Sephton, M.A. (2003). *An Introduction to Astrobiology*. Cambridge University Press and The Open University, Cambridge.

Grinspoon, D. (2003). *Lonely Planets: The Natural Philosophy of Alien Life*. HarperCollins, New York.

Gunn, J. (1972). *The Listeners*. BenBella Books, Dallas, TX.

Guthke, K.S. (1990). *The Last Frontier: Imagining Other Worlds from the Copernican Revolution to Modern Science Fiction*. Cornell University Press, Ithaca, NY.

Hanegan, N.L., Price, L. & Peterson, J. (2008). Disconnections between teacher and students in bioethics. *Sci. Educ*. **17**, 8–9.

Hennessey, R. (1999). *Worlds Without End: The Historic Search for Extraterrestrial Life*. Tempus Publishing, Charleston, SC.

Hurd, P.D. (1998). Scientific literacy: New minds for a changing world. *Science Education* **82**, 407–416.

Jackson, R. (1992). *UFOs: the sightings of alien people and spacecraft from the earliest centuries to the present day*. Grange Books, London.

Kaufman, M. (2008). Search for alien life gains new impetus. *Washington Post*, July 20, A01. Retrieved 25 July 2008, from http://www.washingtonpost.com/wp-dyn/content/story/2008/07/19/ST2008071902028.html

Kepler, J. (2003). *Somnium*. Dover Publications, New York.

Koerner, D. & LeVay, S. (2000). *Here Be Dragons: The Scientific Quest for Extraterrestrial Life*: Oxford University Press, Oxford.

Koestler, A. (1959). *The Sleepwalkers*. Hutchinson, London.

Kolso, S.D. (2001). Scientific literacy for citizenship: tools for dealing with the science dimension of controversial socioscientific issues. *Sci. Educ*. **85**, 291–310.

Krauss, L.M. (1995). *The Physics of Star Trek*. HarperCollins, New York.

Krauss, L.M. (1997). *Beyond Star Trek*. HarperCollins, New York.

Kremer, K., Urhahne, D. & Mayer, J. (2008). Relationship between students' general and theory-specific beliefs on the nature of science. Paper presented at the *National Association for Research in Science Teaching* (*NARST*) *International Meeting*, Baltimore, MD.

Kuhn, A. (1990). *Alien Zone: Cultural Theory and Contemporary Science Fiction Cinema*. Verso, New York.

Lanza, T. & Negrete, A. (2007). From myth to Earth education and science communication. *Geol. Soc. Special Publ*. **273**, 61–66

Lederman, N.G., Abd-El-Khalick, F., Bell, R.L. & Schwartz, R.S. (2002). Views of nature of science questionnaire: toward valid and meaningful assessment of learners' conceptions of nature of science. *J. Res. Sci. Teach*. **39**(**6**), 497–521.

Lunine, J.I. (2005). *Astrobiology: A Multidisciplinary Approach*. Addison-Wesley, San Francisco, CA.

Machado, C.A. (2005). Science fiction and its application in education. *PhD Dissertation*. Pontifícia Universidade Católica do Rio de Janeiro, Brazil.

Mann, G. (2001). *The Mammoth Encyclopedia of Science Fiction*. Carroll & Graf, New York.

Matthews, M. (1994). *Science Teaching: The Role of History and Philosophy of Science*. Routledge, New York.

McComas, W.F., Clough, M.P. & Almazroa, H. (1998). The role and character of the nature of science in science education. *Sci. Educ*. **7**(**6**), 511–532.

McComas, W.F. & Olson, J.K. (1998). The nature of science in international standards documents. In *The Nature of Science in Science Education: Rationales and Strategies*, ed. McComas, W.F. Kluwer, Dordrecht.

Michaud, M.A. (2007). *Contact with Alien Civilizations: Our Hopes and Fears About Encountering Extraterrestrials*. Copernicus Books, New York.

Morrison, D. (2001). The NASA Astrobiology Program. *Astrobiology* **1**, 3–13.

Morrison, D. (2002). Contents of Astrobio 101. *Astrobiology* **2**(**4**), 469–470.

NAI – NASA Astrobiology Institute (2008). *What is Astrobiology?* Retrieved 25 July 2008, from http://nai.arc.nasa.gov/astrobio/what_astrobio.cfm

Negrete, A. (2002). Science via fictional narratives: communicating science through literary forms. *Ludus Vitalis* **10**(**18**), 197–204.

NRC – National Research Council (1996). *National Science Education Standards*. National Academies Press, Washington, DC.

NRC – National Research Council, Committee on the Limits of Organic Life in Planetary Systems, & Committee on the Origins and Evolution of Life (2007). *The Limits of Organic Life in Planetary Systems*. National Academies Press, Washington, DC.

NSTA – National Science Teachers Association (2003). *Standards for Science Teacher Preparation*. Retrieved 25 July 2008, from http://www.nsta.org/pdfs/NSTAstandards2003.pdf

Oliveira, C.F. (2008). Astrobiology for the 21st Century. *Commun. Astron. Public* **2**, 24–25.

Oliver, C.A. & Fergusson, J. (2007). Astrobiology: a pathway to adult science literacy? *Acta Astronautica* **61**(**8**), 716–723.

Olson, J.K., Clough, M.P., Vanderlinden, D. & Kruse, J.W. (2008). Should "proof" and "truth" be targeted first? Evidence for addressing some nature of science concepts and misconceptions earlier than others. Paper presented at the *National Association for Research in Science Teaching* (*NARST*) *International Meeting*, Baltimore, MD.

Pickover, C. (1998). *The Science of Aliens*. Basic Books, New York.

Prather, E.E. & Slater, T.F. (2002). An online astrobiology course for teachers. *Astrobiology* **2**(**2**), 215–223.

Pringle, D. (1996). *The Ultimate Encyclopedia of Science Fiction*. Carlton, London.

Rabkin, E.S. (1983). *Science Fiction: A Historical Anthology*. Oxford University Press, Oxford.

Rose, M. (1982). *Alien Encounters: Anatomy of Science Fiction*. Harvard University Press, Cambridge.

Rubadeau, D.O. & Rubadeau, R.J. (1983). *Guidelines for Grading*. College of New Caledonia, Centre for Improved Teaching, Prince George, British Columbia.

Sagan, C. (1979). *Broca's Brain*. Random House, New York.

Sagan, C. (1985). *Contact*. Pocket Books, New York.

Sagan, C. (1986). *The Dragons of Eden: Speculation on the Evolution of Human Intelligence*. Ballantine Books, New York.

Sagan, C. (1997). *The Demon-Haunted World: Science as a Candle in the Dark*. Ballantine Books, New York.

Sagan, C. & Page, T. (1972). *UFOs: A Scientific Debate*. Norton, New York.
Sagan, C. & Shklovskii, I.S. (1966). *Intelligent Life in the Universe*. Dell, New York.
Sapp, J., Carrapiço, F. & Zolotonosov, M. (2002). Symbiogenesis: the hidden face of Constantin Merezhkowsky. *History Philos. Life Sci.* **24(3–4)**, 413–440.
Sardar, Z. & Cubitt, S. (2002). *Aliens R Us: The Other in Science Fiction Cinema*. Pluto Press, London.
SETI Institute (2008). *The Search for Extraterrestrial Intelligence*. Retrieved 25 July 2008, from http://www.seti.org/
Shamos, M.H. (1995). *The Myth of Scientific Literacy*. Rutgers University Press, Piscataway, NJ.
Shermer, M. (1997). *Why People Believe in Weird Things*. Freeman, New York.
Shermer, M. (2000). *How We Believe*: Owl Books, New York.
Shostak, S., Bennett, J. & Jakosky, B. (2003). *Life in the Universe*. Addison-Wesley, New York.
Sitchin, Z. (1976). *The 12th Planet*. Harper, New York.
Slater, T.F. (2006). Capturing student interest in astrobiology through dilemmas and paradoxes. *J. Coll. Sci. Teach.* **35(6)**, 42–45.
Staley, J.T. (2003). Astrobiology, the transcendent science: the promise of astrobiology as an integrative approach for science and engineering education and research. *Curr. Opin. Biotechnol.* **14**, 347–354.
Sullivan, W.T. & Morrison, D. (2008). Teaching astrobiology to undergraduates and graduate students. *Astrobiology* **8(2)**, 456–460.
Tarter, J. (2001). The Search for Extraterrestrial Intelligence (SETI). *Annu. Rev. Astron. Astrophys.* **39**, 511–548.
Taylor, K. (2002). *Is Imagination More Important than Knowledge?* Times Higher Education. Retrieved 25 July 2008, from http://www.timeshighereducation.co.uk/story.asp?storyCode=172613
TED (2006). *Sir Ken Robinson: Do Schools Kill Creativity?* Retrieved 25 July 2008, from http://www.ted.com/index.php/talks/ken_robinson_says_schools_kill_creativity.html
Temple, R. (1976). *The Sirius Mystery: New Scientific Evidence of Alien Contact 5,000 Years Ago*. St. Martin's Press, New York.
Voltaire. (1989). *Micromegas*. Dedalus, Sawtry.
von Däniken, E. (1968). *Chariots of the Gods*. Bantam, New York.
Ward, P. & Brownlee, D. (2000). *Rare Earth: Why Complex Life is Uncommon in the Universe*. Copernicus Press, New York.
Webb, S. (2002). *If the Universe is Teeming with Aliens … Where is Everybody? Fifty Solutions to the Fermi Paradox and the Problem of Extraterrestrial Life*. Copernicus Books, New York.
Wells, H.G. (2005) *The War of the Worlds*. London, Penguin Books.
Zindell, D. (1989). *Neverness*. Bantam Books, New York.