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Teaching Astrobiology in a Sustainability Course

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Abstract Sustainability education typically focuses on sustaining life, ecosystems, and humans here on Earth. However, important insights come from considering life beyond Earth. This article presents several ways to teach astrobiology – the study of life in the universe – in an undergraduate sustainability course. The concept of habitable zones offers perspective on the temporal and spatial scales of sustainability on Earth and beyond. The prospects for long-term sustainability in the universe suggest expanded conceptualizations of sustainability, leading to a present-day focus on the risk of certain global catastrophes. Finally, the possibility of extraterrestrial life and the fact that none has yet been observed gives us new ways of thinking about our own lives on Earth. In sum, astrobiology offers an understanding of how our current sustainability challenges fit within the grander scheme of the universe. This understanding is of great value to the sustainability classroom.

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Introduction

In both research and teaching on sustainability, the focus is almost always on sustainability here on Earth. In doing so, we neglect the broader universe in which our home planet resides. Earth is not a closed system, and while it is often useful to approximate it as such, much can be learned about sustainability from considering the rest of the universe. Most importantly, we gain invaluable perspective on how our efforts to achieve sustainability on Earth today fit into the grander scheme of things. Only by considering the rest of the universe can we appreciate our place within it. Therefore, it is important to integrate astrobiology – the study of life in the universe – into education for sustainability.

There are additional reasons why astrobiology is important to education for sustainability. Astrobiology offers some very basic insights into what can and cannot be sustained across a broad range of spatial and temporal scales. These insights have major implications for how we understand and approach sustainability – implications that students should be aware of. Additionally, our universe is a fascinating place and studying it raises some very deep and fascinating questions. Integrating astrobiology into any course, including a sustainability course, can help motivate student enthusiasm for learning. Finally, astrobiology is an unusual topic to cover in a sustainability course, thereby challenging students to think critically about the topic and about their broader understanding of sustainability. This article develops several ways in which astrobiology can be integrated into an undergraduate sustainability course via lectures, readings, and an essay question. This astrobiology content serves to enhance a course that is mainly focused predominantly on traditional, Earthly sustainability topics.

Astrobiology and Astrobiology Education

The NASA Astrobiology Institute defines astrobiology as “the study of the origin, evolution, distribution, and future of life in the universe” (NAI 2008). Astrobiology research explores both life on Earth and possible life beyond Earth. Astrobiology, much like sustainability, is a relatively new and emerging field of study within academia (as compared with traditional fields such as biology, geography, and physics), though both astrobiology and sustainability cover topics that have fascinated humanity for ages, including in a rich science fiction tradition. Also like sustainability, astrobiology strives for a holistic understanding of interactions between biological and non-biological systems, and thus is an interdisciplinary or transdisciplinary field. Astronomy, biology, chemistry, and geology are particularly prominent in contemporary astrobiology, but a wide range of other fields also contribute, including engineering, philosophy, psychology, and religion. There have also been a handful of studies connecting astrobiology to sustainability (Tonn 2002; Martinez-Frias 2010).

Astrobiology asks some very big picture questions. Where did Earth life come from? Is there other life out there in the universe? How might we be able to communicate with extraterrestrial civilizations? If we encounter an extraterrestrial civilization, how can, and should, we respond? Can, and should, we colonize other planets, or other parts of our galaxy? How much longer can we survive on Earth? What are the most extreme environments in which life persists? These and other questions form the core of what astrobiologists study.

Given how deep and compelling its questions are, it is no surprise that astrobiology can capture the imaginations of many people. Motivated by this circumstance, astrobiologists have placed relatively heavy emphasis on education initiatives, both within universities and in K-12 and public outreach settings. Astrobiology's public outreach spirit is epitomized by the work of noted astrobiologist Carl Sagan. The education initiatives are motivated largely by the fact that astrobiology holds broad appeal and can capture imaginations, making for many excellent teaching and learning opportunities.

There is also a substantial literature on astrobiology education. Staley (2003) provides an excellent introduction to astrobiology teaching and research, emphasizing its "transcendent" (essentially transdisciplinary) nature. Dartnell and Burchell (2009) provide a broad overview of astrobiology research and education worldwide, with emphasis on the UK, noting the rapid growth in the discipline. Oliveira (2008) presents a concise argument that astrobiology education should be used to increase general scientific literacy because astrobiology is transdisciplinary, fascinating, and raises deep questions about science and its limitations. Zeilik (1973) documents the strong interest in astrobiology topics from students who are not astrobiology specialists.

Pedagogical discussions of astrobiology are available for a range of academic levels. Astrobiology has been used to promote science literacy and interest in science in K-12 education (Allner et al. 2010; MacLeish et al. 2001; Oliver and Ferguson 2007), undergraduate education (MacLeish et al. 2001, 2008; Oliveira and Barufaldi 2009; Slater 2006; Sullivan and Morrison 2008), and even adult education (Brake et al. 2006). Foster and Drew (2009) discuss an introductory undergraduate course in astrobiology. Oliveira and Barufaldi (2009) discuss an undergraduate astrobiology course for non-majors. The paper gives a detailed description of course content, including textbooks used. The course has a stronger science focus than the sustainability course discussed here, but has several common astrobiology topics. An excellent bibliography on astrobiology education and astrobiology in general is included.

Contemporary astrobiology education draws primarily on natural science disciplines such as astronomy, biology, and geology, and often incorporates some engineering. The social sciences and humanities, though nominally relevant, do not get at all as much attention. One notable exception is the science fiction program at the University of Glamorgan (Brake et al. 2006; Griffiths 2004). This program provides much more balance across the major divisions of academia. A second exception is the sustainability content presented in this article, which is based in a social science course on sustainability.

The Course

The astrobiology content presented here was developed for an introductory, general education undergraduate course on geographic perspectives on sustainability and human-environment systems. The course teaches social science as it is relevant to environmental sustainability. Students come from all class years and many majors.

Table 1 presents a summary of course topics. Astrobiology topics are covered in weeks 1, 5, and 14. In week 1 the astrobiology topic is habitable zones; this topic is covered in lecture without reading assignments. In week 5 the astrobiology topic is long-term sustainability; this topic is covered in lecture and supplemented with the reading found in Appendix 2. In week 14 the astrobiology topic is “beyond Earth” which revisits habitable zones and long-term sustainability and then discusses space colonization and the Fermi Paradox. Astrobiology readings for week 14 are two short readings on space colonization (BBC News 2006; Mars Society 1998) and one on the Fermi Paradox (Haqq-Misra and Baum 2009a). Content throughout the rest of the course covers typical sustainability and human-environment systems topics. As Table 1 indicates, the astrobiology content is a relatively small portion of the course and still leaves room for plenty of traditional Earth-oriented topics. The astrobiology content is intended to enhance the study of sustainability, not dominate it.

Week	Topic
1	Course Introduction, Habitable Zones, Environmental Determinism
2	Global Environmental Change & Systems Analysis
3	Sustainability In Our Local Community
4	Environmental Ethics & Sustainability
5	Long-Term Sustainability & Ecological Footprints
6	Collective Action, I=PAT
7	Technological Change, Midterm
8	Climate Change Science
9	Climate Change Impacts & Policy
10	Energy
11	Political Ecology
12	Buildings, Transport, & Cities
13	Food & Agriculture
14	Current Events, Beyond Earth
15	Course Synthesis
16	Final Exam

Table 1: Overview of course topics. Astrobiology is covered during weeks 1, 5, and 14.

Where and When Can Life Be Sustained?

The course begins with the beginning: the Big Bang, about 14 billion years ago. Then, about 12 billion years ago, planets began to form. Earth formed about 4.5 billion years ago. Life on Earth began about 4 billion years ago. Photosynthesis made oxygen abundant in the atmosphere about 2.5 billion years ago. Over the last several hundred million years, plants and then animals colonized land and also experienced several major extinction events. Humans evolved over the last several million years. Or at least, this all is what the available evidence suggests – technically, we cannot rule out the possibility that our origins occurred differently. This technicality points to a rich conversation between astrobiology and religion that can be worthwhile (see Haqq-Misra 2009) but is beyond the scope of this article.

Having established where life came from (or at least where we appear to have come from), the course then discusses where and when life can be sustained. The core concept here is the habitable zone. A *habitable zone* is simply a region in space and time in which life, or certain forms of life, can exist. For sustainability, it is worth distinguishing between habitable zones for life in general and habitable zones for human life; we'll call these *life-habitable* and *human-habitable*. A human-habitable zone is necessarily a subset of a life-habitable zone. Also, since habitable and inhabitable mean the same thing, it is helpful to use the unambiguous term "not habitable" to refer to regions in which life cannot exist. In general, habitable zones occur when conditions are within some agreeable range. For example, temperatures cannot be too hot or too cold – they must be just right. The need for conditions to be "just right" is known as the "Goldilocks Principle", in honor of the famed fairy tale.

Habitable zones exist across many scales. At the galactic scale, we find that for solar systems to be life-habitable, they must be within a spatial and temporal zone with just the right amount of metal, enough time for planets to form, and not too many destructive supernovae (Figure 1). At the planetary system scale, we find that for planets (or moons) to be life-habitable, they must be at a spatial distance from the star such that the temperature is not too hot or too cold (Figure 2). At the planetary scale, we find that life on Earth can exist all across the planet, but that human civilization can in general only exist with just the right amount of water (i.e. not in oceans, or in very dry deserts), or in the very cold polar regions (Figure 3).

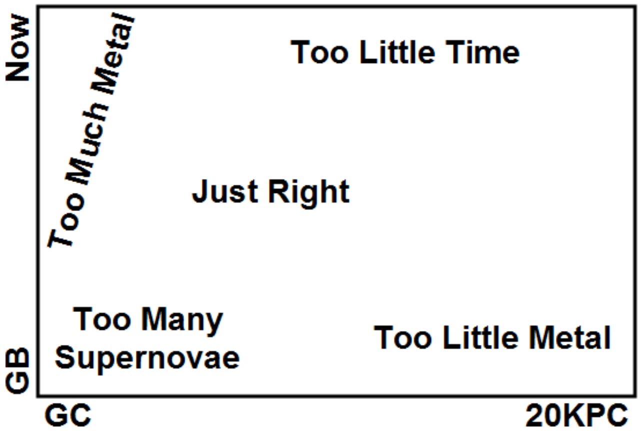

Figure 1: Illustration of the Goldilocks Principle at the galactic scale: the life-habitable zone within our galaxy. GB is the galaxy's beginning time; GC is the galaxy's spatial center; 20 KPC is 20 kiloparsecs, which is equivalent to about $6.2*10^{17}$ *kilometers. Adapted from Lineweaver et al. (2004, 61).*

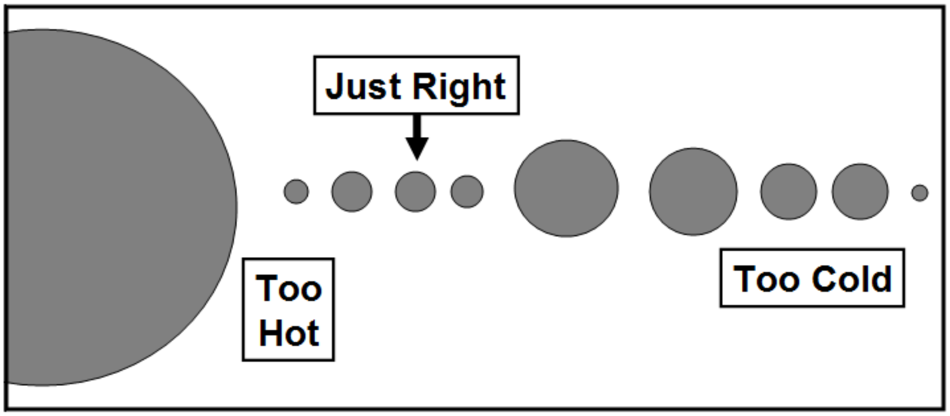

Figure 2: Illustration of the Goldilocks Principle at the planetary system scale: the life-habitable zone within our Solar System. Note: objects and distances in the figure are not drawn to scale.

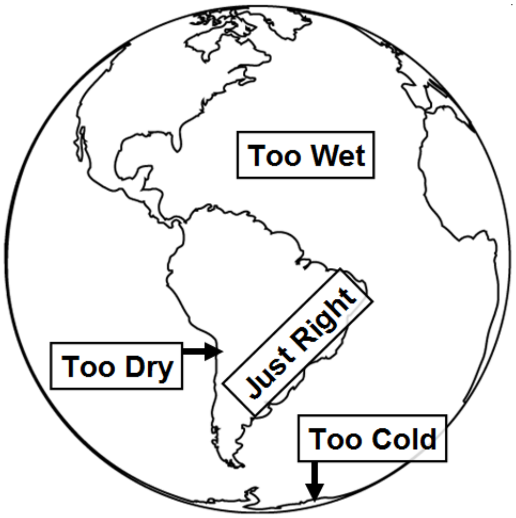

Figure 3: Illustration of the Goldilocks Principle at the planetary scale: habitable zones for human civilization on Earth. The "too dry" area refers to the Atacama Desert; the "too cold" area refers to Antarctica; the "just right" area refers to the Atlantic coast of South America, which is that continent's most densely populated region.

This simple introduction to habitable zones brings several noteworthy learning moments. First, the sequence of galaxy/planetary system/planet can be used to introduce the concept of scale, which is a very central concept in sustainability. Figures 1-3 illustrate habitable zones in these three scales. One can imagine zooming in further to even more local sales. For example, the sheer slopes of Brazil's Pão de Açúcar (Sugarloaf Mountain) are uninhabitable to human civilization, despite being located in the booming city of Rio de Janeiro. Understanding scale will be helpful for students in many ways, including for subsequent lessons on sustainability-astrobiology connections.

Second, the idea of habitable zones leads directly to the idea of environmental determinism. With the study of environmental determinism, the key question is the extent to which human civilization is determined by environmental factors. A strict environmental determinist would argue that civilization is completely determined by environment, whereas a strict rejecter of environmental determinism would argue that civilization is instead determined by human agency. Much middle ground exists between these two positions. However, analysis of environmental determinism has focused primarily on environments on Earth's surface. Clearly, civilization (as we know it) must exist in a human-habitable zone within the galaxy. Therefore, environmental factors determine whether or not it is physically possible for civilization to exist. However, humans can also develop technological and social practices that enable us to exist where we otherwise couldn't. For example, we can bring water with us into the desert, and we can build submarines permitting us to explore deep oceans. This space for human agency within strict astrobiological constraints resembles the idea of environmental possibilism, which suggests that the environment limits what is possible for human civilization but that civilization has broad (though not unlimited) agency within these limits. As discussed below, our ability to expand the regions that we can live in is vital to our prospects for long-term sustainability.

Long-Term Sustainability

Astrobiology plays an important role in how sustainability is defined and conceptualized in the course. There exist many conceptualizations of sustainability, varying on such matters as what it is we strive to sustain (e.g. life, ecosystems, humans) and how long to sustain them for (e.g. centuries, millennia, forever). Usually, it is assumed that these things are to be sustained on Earth. A broader astrobiological perspective leads to a richer conceptualization of sustainability.

Simply put, the world is going to end. It will end in the sense that it will become not life-habitable (and in other senses as well). It will end because the sun will gradually get hotter and larger. The physics of the evolution of stars is fairly well understood. Depending on how the sun's changes interact with ecological and other Earth systems, Earth will become not life-habitable in a few hundred million to a few billion years from now. In a few hundred million years, rising temperatures can reduce the amount of carbon dioxide in the atmosphere via rock weathering, so much that plants might no longer have enough CO_2 for photosynthesis. In a few billion years, the sun will expand so much that it will literally engulf the planet in flames. (For comparison purposes, life on Earth began about 4 billion years ago and humanity evolved over the last several million years, as noted above.) Beyond then, life (human or otherwise) cannot be sustained on this planet.

The end of the world is not the end of hope for sustainability. While Earth will become not life-habitable within the next few billion years, the rest of the universe will remain life-habitable. At first, other planets and moons in our own solar system could find themselves in a life-habitable zone. If our technology can permit it, this zone could include a human-habitable zone as well (see below for further discussion). These newly habitable places would be the planets and moons that are farther from the sun. Eventually, these places would cease to be life-habitable, as would all other places in our solar system. But other solar systems would still be life-habitable, and probably also human-habitable. And when no more solar systems are habitable, there may still be other options available.

The end of the universe is not as well understood as the end of the world is. The physics here simply remains unresolved. In the context of sustainability, the key question is how long we can sustain whatever it is that we care about, be it life, ecosystems, humans, or something else. Some analyses suggest that we can sustain these things for about 10^{32} more years, until protons start decaying. Other analyses suggest that we can sustain these things forever, either in this universe, or perhaps by creating a wormhole to travel to another universe.

While we do not know how long the universe will remain habitable, we can be quite certain about one key detail: the universe will remain habitable for much, much longer than Earth will. In other words, it is a small world after all, but it is a really large universe. Almost all of the opportunity for those things that we care about lies beyond Earth. From this perspective, the billion or so years that we can inhabit Earth is the short term. The long-term is the period in which we will need to live elsewhere in the universe (Figure 4).

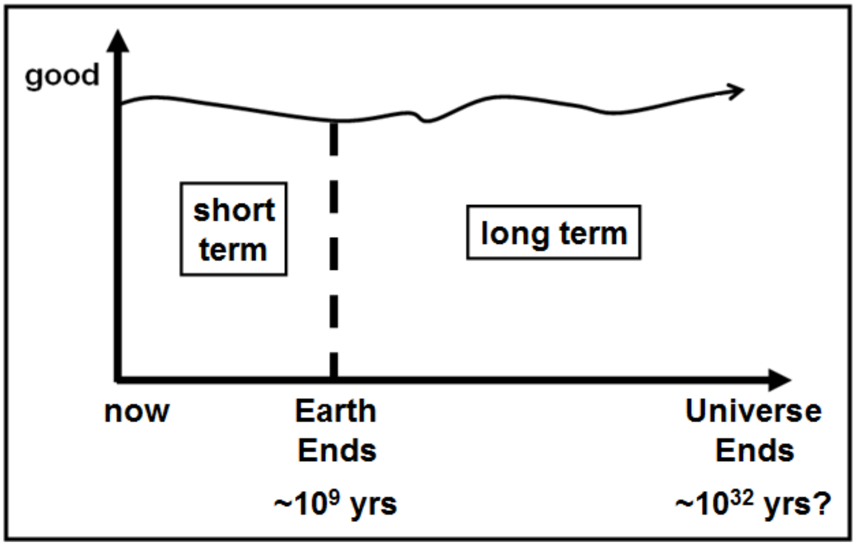

Figure 4: Illustration of short-term and long-term sustainability. The horizontal axis shows time; the vertical axis shows "good", i.e. whatever it is that we care to sustain, such as life, ecosystems, or humans.

Since the world will end, long-term sustainability requires that we colonize space. In other words, we must expand the region we can inhabit so that it extends beyond Earth: we must colonize space. Just as humans have developed technological and social practices to expand our habitable zones on Earth, we may be able to do the same for zones beyond Earth. First we may be able to go to the planets and moons that are farther from our sun but still in our solar system, such as Mars or Titan. Eventually, we would need to travel to other solar systems. At some more distant time, we would probably need to find ways of surviving without stars. All this is not to say that we can colonize space. Despite some initial successes in space colonization (and some failures too), the technological feasibility of space colonization remains uncertain. All that is certain – assuming that our understanding of the end of the world is correct – is that sustainability for humanity and for Earth-life more generally requires space colonization. In short, if we do not colonize space, we will die.

Students are introduced to active work on interplanetary travel by reading the Founding Declaration of the Mars Society, a non-profit organization that promotes human travel to Mars (Mars Society 1998). Other topics that could yield course readings or discussions, especially for a course with a strong ecological orientation, include terraforming and Biosphere 2. Terraforming is the process of forming inhabitable ecosystems on other planets. At this time the process remains speculative, though some research has been conducted on its feasibility (see McKay et al. 1991). Biosphere 2 is a structure designed to be a self-contained, human-inhabited biological system which would help humanity learn about, among other things, the feasibility of creating biospheres in space. The project suffered from many pitfalls but nonetheless yielded new insights (see Marino and Odum 1999).

The importance of space colonization has important implications for how we think about sustainability. Eventually sustainability will require space colonization. This holds regardless of whether we strive to sustain humans, ecosystems, or life itself: all of these things will perish when the world becomes not habitable in a billion or so years. If these things are to survive into the long-term, they may require human intervention, since humans could well be the only Earth beings capable of colonizing space. But this does not mean that we should colonize space now. We still have a billion or so years, which should be plenty of time given the rate of technology progress. As long as space colonization is possible (and it probably is), we should succeed at it within the next billion or so years – as long as nothing really bad happens first. If we want to help facilitate long-term sustainability, then we should seek to prevent these really bad things from happening.

What events could be so catastrophic as to prevent us from eventually colonizing space? These events must be so severe that they permanently destroy global civilization. Included here are nuclear warfare, major pandemics, disruptive technologies, and ecological collapse (Bostrom and Ćirković 2008). Students thus should recognize that if they care about long-term sustainability, they should focus on helping avoid these events. Only some work to avoid these events is congruent with what we traditionally think of as sustainable development. Other work is rooted in astrobiology: if we develop a self-sustaining space colony now, then we gain some insurance against catastrophic events that occur on Earth. On this, students read a news article describing physicist Stephen Hawking’s call for space travel (BBC News 2006). Thus, an astrobiological perspective on long-term sustainability helps us reevaluate what our sustainability priorities should be. This perspective is built into the essay question found in Appendix 1.

The possibility of preventing major global catastrophes raises a difficult question: How hard should we try to prevent them? In particular, should we sacrifice any present needs to help prevent catastrophe? For example, should we restrict global trade and travel so as to help prevent pandemics from spreading? Should we overhaul our lifestyles and our industry to avoid ecological collapses via climate change or other phenomena? Finding options that avoid such tradeoffs is a core goal for sustainable development as defined e.g. by the Brundtland Commission: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. But when these win-win options do not exist, what should be done? This is a difficult question and thus well-suited for extended discussion in classroom groups or in writing assignments.

There is one other point worth making about space colonization in the context of sustainability: its relationship to natural resources. Much concern about sustainability is predicated on the classic idea of limits to growth (as in Meadows et al. 1972). A common theme here is that Earth is a finite planet with finite resources, implying that sufficiently rapid growth on the planet cannot be sustained indefinitely. However, some additional resources can be found beyond Earth. For example, asteroids are rich in certain minerals, especially ferrous metals. On this, Lewis (1997, 57) writes “The total mass of available resources not only vastly surpasses expected demands in space, but suffices to support indefinitely a population vastly larger than that of Earth”. (See also Fawkes 2007, noting that space exploration can be a drain on certain resources such as those used for fuel.) While this may be an overstatement (in particular because expanding populations would need resources that cannot be found on asteroids), it remains the case that asteroids and other extraterrestrials bodies contain natural resources. This in turn implies that the limits to growth may not be fully determined by the limits of Earth.

For introductory students, there is little existing content available introducing the astrobiology of long-term sustainability. In response, I wrote a concise summary of the concept for my course, drawing off of recent academic work. This summary was used as a course reading. It is reproduced in Appendix 2 so that it can be used in or adapted for other courses.

Extraterrestrial Life

One additional topic is important in the context of long-term sustainability: the possibility of extraterrestrial life. If there is extraterrestrial life, then perhaps life will be sustained in the long-term even if we fail to colonize space before the world becomes not habitable. This raises the question: does extraterrestrial life exist?

Whether there is life elsewhere in the universe is a core astrobiology question. The universe is very large, and it is full of galaxies, star systems, and planets that have habitable zones. Given how old the universe is, we would expect there to be lots of other life in it. There could easily be life in other galaxies without us ever knowing about it, because galaxies are very, very far apart from each other. But the distances between star systems within galaxies are much smaller, so much that we might expect intelligent civilizations to be widespread throughout our own galaxy.

This leads to a paradox, first developed by physicist Enrico Fermi: if there are intelligent civilizations throughout our galaxy, then where are they?

The Fermi Paradox is a topic of major fascination for researchers, students, and the general public alike. It has been used previously as a pedagogical tool to motivate student learning (Slater 2006). Many solutions to the paradox have been proposed (Ćirković 2009; Webb 2002). While we cannot know for sure which solution(s) explain why extraterrestrial civilizations have not been observed, considering the possible solutions helps us understand our place within the universe. Three Fermi Paradox solutions are particularly important to sustainability (Baum 2010a).

First, civilizations might inevitably destroy themselves when they become sufficiently intelligent to do so. For example, they might discover how to build catastrophic weapons such as our nuclear bombs, and then use them on themselves. This is a very frightening solution, because it suggests that human civilization might soon destroy itself, since we now have the capacity to do so. But perhaps we will succeed where others failed. Our success may well depend on our ability to cooperate peacefully and manage our technology safely. Thus, this Fermi Paradox solution gives us that much more reason to develop these virtues in our students.

The second important Fermi Paradox solution is known as the “Sustainability Solution” (Haqq-Misra and Baum 2009b; for a concise summary appropriate for a course reading, see Haqq-Misra and Baum 2009a). Perhaps other civilizations are out there, but they cannot expand rapidly enough to spread throughout the galaxy. If they tried to expand rapidly, they might bump into the same sorts of sustainability constraints that we face on Earth today. Rather remarkably, this implies that our Earthly sustainability challenges could explain why we have never observed an extraterrestrial civilization. It also implies that our Earthly sustainability efforts could be crucial for civilizations throughout the galaxy.

The third important Fermi Paradox solution is simply that no other intelligent life exists in the galaxy, despite how large the galaxy is. Some astrobiologists believe this to be the case (Ward and Brownlee 2000). What does this mean for sustainability? If human civilization is unique on the galactic scale, then it becomes that much more important for us to achieve long-term sustainability. We may be the galaxy’s (or even the universe’s) only shot at something truly special.

The possibility of intelligent extraterrestrial life offers one other important learning opportunity, on the relations between human and non-human animals. Consider the question: What, if anything, is the nature of the distinction between humans and non-human animals? Humans often cite certain qualities such as intelligence, awareness, and capability to distinguish ourselves from other animals on Earth. But intelligent extraterrestrials could possess these qualities in greater abundance than we do. In the presence of extraterrestrials, we may be, in relative terms, the animals. This possibility in turn raises some significant strategic and ethical considerations (Baum 2010b).

Conclusion

Astrobiology is of considerable importance to sustainability for several reasons and thus should be included in sustainability education. In this paper I have presented how to incorporate various aspects of astrobiology into an introductory undergraduate sustainability course.

One might question the appropriateness of including astrobiology in an introductory course given that astrobiology is not a well-established topic within sustainability. But astrobiology offers strong insights into the general understanding of sustainability, which is what is taught in introductory courses. Furthermore, the specific content presented here is well within the realm of what introductory students are capable of grasping. The material is simple but profound. In my view, college instruction at all levels should be informed by cutting edge ideas. My own students were often enthusiastic to be learning such novel and intriguing ideas. This enthusiasm plus the insights from the astrobiology content make it well worth including in even an introductory sustainability course. Finally, the novel perspective of astrobiology forces students at all levels to critically reexamine their understanding of sustainability; this critical reexamination is of pedagogical value in its own right.

The core pedagogical value of astrobiology in the context of sustainability education lies in its ability to provide an even broader perspective. Sustainability education teaches us to imagine our lives within the context of the broader trajectory of planet Earth. With astrobiology, we can further imagine our lives and our planet within the context of the solar system, the galaxy, and the universe. What we find is that our current sustainability work has a literally galactic significance – and maybe more – especially when it is oriented towards protecting the existence of Earth civilization so that we can colonize space before the world becomes not habitable. The stakes really are that high. I thus end my course with one simple message: Don’t botch this.

Appendix 1: Astrobiology & Sustainability Essay Question

The following is an essay question that provides students the opportunity to integrate astrobiology topics and other sustainability topics into a single, compelling narrative. The question is perhaps the core question in sustainability.

Is humanity doomed? In other words, is the current human population unsustainable? Please answer this question again, drawing on the following topics: (a) The food pyramid; (b) Your course project; (c) A discussion of structure vs. agency; (d) Ecological footprints; (e) The Fermi Paradox; (f) The end of Earth and the universe.

Topics (e) and (f) are from astrobiology course content; topics (a) through (d) are from the rest of the course. The question can be readily customized by choosing which topics to include. If the topics are carefully chosen, students can produce very high quality essays. I have been consistently impressed by the sophistication with which students are able to respond to this question. Quality responses come from students giving any of the possible answers: yes, we are doomed; no, we are not doomed; and maybe, we might be doomed. In my teaching, I aspire to persuade students that whether we are doomed probably depends on how successfully we rise to the challenges of sustainability, but the students, to their credit, are often able to skillfully articulate competing viewpoints.

Appendix 2: Reading on Long-term Sustainability

The following is a concise summary of the astrobiology of long-term sustainability, which works well as an introductory reading on the topic:

A hallmark of sustainability is concern for what happens in the future. Competing definitions of sustainability are generally either *anthropocentric*, where concern is for future humans, *ecocentric*, where concern is for future ecosystems, or a combination of the two.

How long is this future that we might care about, and what does its length mean for us?

We do not know how long the future might be. The physics of the fate of the universe remains very much unsettled. It might or might not be possible for humans, ecosystems, or anything else we might care about to continue existing for an infinite amount of time. What we do know is that these things can continue existing for a very long time, perhaps 10^{32} years.

Earth, however, has a much shorter – but still long – inhabitable lifetime. The physics of Earth's fate is much better understood. In about 500 million years, the sun will be much warmer, possibly ending life on Earth as we know it. In about 5 billion years, the sun will expand and engulf Earth, at which point Earth-life will almost certainly end.

The key detail here is that the universe will be inhabitable for much, much, much longer than Earth will.

Therefore, if we care about the future, it is crucial for whatever it is we care about – humans, ecosystems, etc – to survive beyond Earth's end. This requires that Earth-life colonize space. Space colonization in turn probably requires human civilization (or the civilization of whatever humans might evolve into). After all, humans are already performing some space travel, and no other species is anywhere close.

The eventual necessity of space colonization does not mean that we should focus our current sustainability efforts on space colonization. This is because we have at least 500 million years or so to leave Earth. By then, we should be able to successfully colonize space (assuming it's possible in the first place) – as long as nothing really bad happens first. These "really bad" things are the civilization-ending catastrophes that would prevent us from ever colonizing space. Such catastrophes might include nuclear warfare, pandemic outbreaks, catastrophic climate change, or runaway technology. *Avoiding these catastrophes should be the top priority for anyone wishing to sustain Earth-life – human or otherwise – into the distant future.*

For more on this theme, see Baum (2010a), Bostrom (2003), Bostrom and Ćirković (2008), Posner (2004), Rees (2003), Smil (2005), and Tonn (2002).

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