Complexity and the Origin and Evolution of Life
Teaching "Threshold Five"

by James B. Cunningham

Dominican University of California is a small liberal arts institution located just north of San Francisco.[1] In early 2010 a group of core faculty members endeavored to redesign the University's general education program, including our First Year Experience. It was decided that Big History would serve as the theme of this First Year Experience, consisting of a two-semester program: in the first semester, students study the Big History narrative and take, as the course is described, "an immense journey through time, to witness the first moments of our universe, the birth of stars and planets, the formation of life on Earth, the dawn of human consciousness, and the ever-unfolding story of humans as Earth's dominant species;" in the second semester, students select a topic such as visual arts, human cultures and political

[1] This paper was first delivered as a presentation titled "Complexity and the Teaching of the 5th Threshold: The Origin and Evolution of Life" at the inaugural conference of the International Big History Association (IBHA) at Grand Valley State University in Grand Rapids, Michigan, August 2-5, 2012.

systems, or myth and metaphor, and examine this topic through the lens of Big History.[2] An important component of both semesters is that students work on developing skills in critical thinking, research, and writing. This paper will present how the Dominican faculty teaches the first-semester Big History course—specifically the Fifth Threshold, encompassing the origin and evolution of life—and uses the concept of increasing complexity to teach students about this period.

Since the Fall of 2011 our faculty has used the preliminary edition of *Big History: Between Nothing and Everything* by David Christian, Cynthia Brown, and Craig Benjamin as a course textbook. In their book's introduction the authors suggest that the study of Big History can be a "daunting task," especially for students.[3] However, they go on to suggest that the key to studying Big History is to first lay out a clear overall shape and pattern to the story. The authors propose that the idea of increasing complexity is useful in framing this shape and pattern. In teaching Big History at Dominican we have embraced this idea and use increasing complexity as the thread that ties the whole Big History story together. How do Christian, Brown, and Benjamin define

---

[2] "First Year Experience 'Big History.' " *First Year Experience "Big History."* Dominican University of California. 2012. Web. 7 Jan. 2013.

[3] David Christian, Cynthia Brown, and Craig Benjamin. *Big History: Between Nothing and Everything.* New York: McGraw Hill, 2010, *xi.* Print.

complexity? According to these Big Historians, the first characteristic of complex things is that they are made up of many parts. Second, these parts are arranged in a particular (non-random) way. Third, these parts interact, yielding a result greater than the sum of its parts; we say that these interacting parts have "emergent properties." Fourth and finally, in order to increase complexity and maintain it, energy must flow into and through the system. If there is no energy, entropy increases and complexity decreases.[4]

To provide additional structure to the Big History narrative and help students see the continuity of the story, we have embraced Christian, Brown and Benjamin's idea of dividing Big History into thresholds. "[A] threshold is, literally, a doorsill; it is the point at which, with one small step, you move from the outside to the inside of a house, so a threshold is the point at which a small change gives rise to something entirely new."[5] The eight thresholds we use at Dominican are:

1. Creation of the Universe—"Big Bang"
2. Creation of the First Stars

---

[4] Ibid., *xiv*

[5] Ibid., *xiv*

3. Creation of Chemical Complexity—formation of larger, more complex elements from the first simple elements of Hydrogen and Helium
4. Creation of Earth and the Solar System
5. Creation and Evolution of Life
6. Creation of Human Beings—this encompasses human history during the Paleolithic Era
7. Origin of Agriculture—this covers human history during the Agrarian Era
8. Origin of the Modern World

There are a number of examples of increasing complexity during the early stages of the emergence of life that stand out: for example, the transition of prokaryotic organisms to eukaryotic organisms by the process of endosymbiosis. Not only are eukaryotic cells made up of multiple parts, like mitochondria, chloroplasts, and membrane-enclosed nuclei, those parts also work together in very precise and coordinated ways. As an example, the organism as a whole engulfs food particles, the particles are digested by packets of membrane-enclosed enzymes, and then the digested food is converted into useful energy (ATP) by the mitochondria so that the flagella can propel the whole cell to chase down and engulf more food. All these parts and steps work together to support the survival of the organism.

Additionally, the increase in complexity of eukaryotic cells resulted in specific, emergent properties that were not present in prokaryotic cells. For example, among prokaryotic cells there are no instances of multicellularity in which the cells work together like we see in eukaryotic cells. So, multicellularity is another example of increasing complexity but evolved as a result of the emergent property obtained by prokaryotic cells evolving into eukaryotic cells.

In a recent book by Calcott and Sterelny, *The Major Transitions in Evolution Revisited*[6], the authors discuss the work of Szathmary and Maynard Smith[7] who suggested that these sudden major transitions or emergent properties are caused by changes in the fundamental mechanisms of evolution, namely in how selection operates. Szathmary and Maynard Smith have argued that multicellularity evolved because eukaryotic cells were selected favorably based on group selection as opposed to individual selection. They have suggested that, as described by Sagan[8], eukaryotic

[6] Brett Calcott, Kim Sterelny and Eörs Szathmary. *The Major Transitions in Evolution Revisited.* Cambridge: MIT Press, 2011. Print.

[7] John Maynard Smith and Eörs Szathmáry. *The Major Transitions in Evolution*. New York: W.H. Freeman Spektrum, 1995. Print.

[8] Lynn Sagan. "On the Origin of Mitosing Cells." *Journal of Theoretical Biology*. 14 (1967): 255-274. Web. 7 Jan. 2013.

cells are, in theory, communities of interacting prokaryotic cells and thus their evolution should be controlled by group selection rather than individual selection.

During the early evolution of life there are further examples of increasing complexity at the ecosystem level. Ecosystems are defined as groups of species living and interacting in a particular time and place. The earliest ecosystem on earth was simple and consisted of only one trophic level namely heterotrophs, which fed on the content of the "primordial soup" of Earth's early ocean. As the nutrients in the primordial soup were depleted and competition for the remaining nutrients increased, some organisms may have evolved other ways of acquiring energy (example: harvesting energy from the sun or from compounds associated with thermal vents.) These types of organisms are referred to as autotrophs. So a second ecosystem evolved on earth consisting of two trophic levels of organisms, one heterotrophs and the other autotrophs. As time passed, rising diversity of heterotrophs and autotrophs resulted in an increasing complexity of the ecosystem.

Besides the four characteristics of complexity already mentioned above, systems that become more complex also exhibit an increase in energy efficiency. This is not a new idea but was discussed by Fred Spier in his book *Big History and the Future of Humanity*. As systems become more complex, their parts—while increasing in number—continue to share a finite amount of energy. This results in a greater level of competition between these parts. This is what ecologists refer to as "resource (or niche) partitioning." Niches are often described as the occupation of the species or how the species makes a living. Niche partitioning results in species becoming specialists and, I am suggesting here, more efficient at acquiring necessary energy and resources.[9]

Are there examples of increased efficiency during the early evolution of life? I believe so. As mentioned above it is thought that the first organisms were heterotrophs, and, due to a lack of oxygen in the early atmosphere, they very likely utilized a form glycolysis to acquire energy from the "primordial soup." Glycolysis provides only a limited amount of energy because it only partially brakes down nutrients, leaving behind wasted chemical energy as a bi-product. With the evolution of eukaryotic cells and their mitochondria—in addition to the accumulation of oxygen in the atmosphere—these cells were able to more completely break down their food and, in doing so, generate significantly more energy. Thus, cells evolved to more efficiently convert chemical energy in their food to a form of energy used to grow, move and reproduce.

Why is it important to use the concept of increasing complexity to teach Big History and, in particular, the Fifth Threshold? I feel there are several reasons. First,

---

[9] Fred Spier. *Big History and the Future of Humanity*. Oxford: Wiley-Blackwell Publishing, 2011. Print.

as mentioned from the start, an emphasis on increasing complexity provides students with a framework and way of making sense of the entire history. The Thresholds of increasing complexity provide students with easy-to-remember road signs along the timeline.

Emphasizing increasing complexity specifically in the Fifth Threshold helps students see that the origin and evolution of life—and therefore their own lives—is a continuation of what came before. We truly are a product of supernovae explosions and are made up of stardust. It also underscores the connection we have with the rest of creation. We modern humans have become very detached from our environment. For example, we live and work in buildings that insulate us from environmental changes such as fluctuations in sunlight and temperature. Anything that can help us see the connection between our lives and the rest of the universe is beneficial. This is the potential of Big History.

We conclude the first-semester Big History course by asking students to speculate on the future of the universe. We remind them of the pattern of increasing complexity and the eight thresholds that we have discussed throughout the semester and ask them to speculate on what might be the next threshold in complexity. As mentioned above, increases in complexity and the maintenance of this complexity require the input of energy, and we as a species are using more and more energy all the time. I am suggesting, however, that this energy is derived by large extent from systems that are highly simplified. Sustaining these simplified systems requires enormous energy input. In addition, because these systems are simplified, they are extraordinarily inefficient energy-users. For example, in order to generate a more sustainable way of producing energy to operate cars and other vehicles, we produce ethanol. To a large extent ethanol is produced from corn. So we grow corn in huge monocultures, which represent very simplified ecosystems. To maintain these monocultures of corn we must expend energy to fertilize, irrigate, and control pests, etc. Without this input the corn monoculture would disappear. The amount of energy going into the growth of corn is greater than the energy we get out to maintain our complex society. From a cost/benefit point of view this makes no sense. This type of analysis is termed "determining the true cost of a resource" by environmental scientists. The obvious problem with this situation is that the main energy source we are using to keep our simplified systems going is oil, a finite energy source. So perhaps what is coming next is discovering ways of generating the energy we need to maintain our complex way of life from systems that are not artificially simple. With an emphasis on increasing complexity, particularly in their study of the Fifth Threshold, these conclusions become self-evident for our students and lead to a more cohesive, contingent understanding of the Big History timeline.

Ornithologist, biologist, ecologist, and zoologist Dr. James Cunningham holds a PhD in zoology from the University of Canterbury in Christchurch, New Zealand. He has performed extensive research on native birds of New Zealand and authored numerous publications on the subject. Since 1991, Dr. Cunningham has taught courses on human anatomy and physiology, marine biology, natural history of California, freshwater and terrestrial ecology, environmental ecology, animal behavior, and genetics at Dominican University of California.