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Big History's Risk and Challenge

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Some twenty years ago, a scattered few, intrepid historians began teaching courses on a wider, slightly precarious stage. They realized that much good and valid history extends far back in time, well prior to the ancient civilizations of Egypt and Sumer thousands of years ago, even beyond the onset of hominins millions of years ago. These "big historians" were thinking expansively, deliberately—in both space and time—identifying and linking many notable events in the deep past, from the origin of the universe to the present day on Earth.

It was as though, while trekking up a mountain whose summit holds true knowledge, the big historians began realizing there's much more to history than we had been led to believe by world, global, or traditional historians who have dominated historiography for decades. Pioneers like John Mears of Texas, David Christian of Australia, Fred Spier of Holland, and Cynthia Brown of California strove to grasp a broader view of who we are and whence we came. They were searching for humanity's sense of place in the larger scheme of things, attempting to understand how relatively recent happenings on Earth might relate to events that occurred long before any written records.

Yet hardly a decade ago, those same big historians, much enthused by their new story-telling agenda, discovered a different breed of scholars on the other side of the mountain. These were mostly astronomers, uncommonly eclectic researchers who had explored for much of the twentieth century much the same cosmology, relating it in articles, books, and classrooms well earlier than had the big historians. These natural scientists, who subscribe to the modern scientific method and who demand experimental or observational tests of their ideas before proceeding, often call their grand narrative "cosmic evolution," but it's also sometimes known as universal evolution, epic of evolution, astrobiology, or simply as the late-Renaissance term natural history.

It doesn't matter who was first or is better equipped to describe the awesome story of our origins. In the metaphor above, most scholars generally advance while hiking the mountain of knowledge; there are many ways to learn about ourselves and our world, including art, music and literature, as well as history and science. Although some humanists on one side and scientists on the other draw nearer—not only as the lateral space dividing us literally lessens while approaching the peaked summit, but also as our subject matter and research methodologies increasingly overlap—neither party, indeed no one, will likely ever actually reach the peak; absolute truth is probably unattainable. Rather, the very act of questing for answers to deep and abiding inquiry means that serious scholars often gain better approximations of reality.

Meanwhile, philosophers and theologians, both amused and concerned, wonder wearily from

mountainous ledges how the latest findings might impact their thoughts and beliefs that require no tests. Will neither thinking alone nor believing alone, as many scientists like myself profess, ever make the unknown known?

The Grand Scenario of Cosmic Evolution

Evolution—ascent with change of nature's many varied complex systems—has become a powerful unifying concept throughout the sciences. In its broadest sense, cosmic evolution, which includes the subject of big history, comprises a holistic explanatory narrative of countless changes within and among organized systems extending over about fourteen billion years from the big bang to humankind. Its working hypothesis is that all complex systems seem governed by common processes and properties, as though simple, underlying (perhaps unchanging) Platonic forms pervade the cosmos. This interdisciplinary scenario has the potential to unite the triumvirate of modern learning—humanities, natural science, and social studies—thereby creating for people of all cultures at the start of the new millennium a consistent, objective, and comprehensive worldview of material reality.

A handful of natural scientists have long told the cosmic-evolutionary story based on the latest experimental and observational findings; most are scholastic mavericks committed to interdisciplinary research at the frontiers of science. They tend to de-emphasize humanity in the huge sweep of this lengthy and inclusive narrative, giving substantial coverage to galaxies, stars, planets, and other-life forms that surround us on Earth (and perhaps beyond). They are especially careful not to state or imply any kind of anthropocentrism, often stressing the "front" of this universal story that has little to do specifically with us yet is vitally important to the whole shebang. For the cosmic evolutionist, the unvarnished origins epic is not just about us—nor even mostly about us—although we are assuredly the current storyteller. In short, if humans did not exist, this grand narrative would still unfold, from quarks to quasars and from microbes to minds all across the universe. The arrow of time that maps this amazing scenario's prodigious events is not likely pointing at us.

By contrast, historians, being humanists largely, emphasize humanity. It's understandable, given the root *his-story*, much as Pope long ago declared "the proper study of mankind is man itself." Accordingly, even big historians stress human accomplishments and their cultural achievements, relating more recent times near the "back" of the story: "human history in its wider context" (Christian 2005) or "an approach to history that places human history within the context of cosmic history" (Spier 2011). Yet they are also rightly intrigued by salient features of our Milky Way Galaxy, our parent star the Sun, our home planet Earth, and myriad life forms that specifically (yet meanderingly) led to our ancestors thousands of generations ago. In short, again, if humans did not exist, both big historians and their more limited story clearly starring us would evaporate. To most big historians, big history itself is naturally anthropocentric—to them, it's unapologetically *our* story.

To compare and contrast this yin-yang take on anthropocentrism, imagine two movies that

project the main events of the same big-bang-to-humankind plot, yet at different speeds. One movie portrays fourteen billion years linearly, treating each billion years of real time in a single minute of screen time; this is the way cosmic evolutionists model the cosmos—so many galaxies over so much time, Earth debuting with hardly a third of the film left, and humans appearing within only the last second of the movie. Yet some viewers despair; the story is so long, our existence so brief, how can it be? Alternatively, we could create for ourselves more than a cameo appearance by running time non-linearly (logarithmically) and here such a movie allows Earth and life to enter earlier, indeed ensuring that humankind plays a leading role; this is the way big historians typically view the cosmos—stressing events that are better known and closer to home in both space and time.

Actually, these contrasting movies need not be merely imagined, for they already exist as short films that are freely accessible at compressed-resolution over the Internet: http://www.cfa.harvard.edu/~ejchaisson/cosmic_evolution/docs/fr_1/fr_1_intro_movies.html I helped make both of them as part of a course that I've taught for nearly four decades, mostly at Harvard University. In the mid-1970s, astrophysicist George Field kindly invited me to join him in co-creating a course on cosmic evolution that quickly became a huge and popular offering often filling the largest lecture hall on campus. Students were clearly "voting with their feet" while searching for an intellectual worldview, and they were also rewarding us for taking the fine art of teaching seriously in a place where that's not often done. Nowadays, I enjoy teaching this same course (suitably revised and updated) in Harvard's Extension School, which appeals to smaller audiences of mature adults in interactive seminars.

The essence of this cosmic-evolutionary course has been taught at the Harvard Observatory for nearly a century. Harlow Shapley, who began teaching what he called "Cosmography" in the 1920s, was one of the first to recognize the widespread evolution of animate and inanimate systems throughout the history of the universe. For several decades, he conveyed this scientific story to legions of undergraduates (in the same auditorium where I still teach it now), after which the torch was passed to my observatory predecessor, Carl Sagan, who famously taught much the same broad theme, initially at Harvard and then at Cornell, entitling his course "Life in the Cosmos." He was not alone; Hubert Reeves in France, Iosif Shklovsky in Russia, Erich Jantsch in Austria, among a few other pathbreaking scientists in the 1960s and 70s, expansively described the evolutionary epic in words, if not its technical ways and means.

Sharp students and intelligent taxpayers alike, both seeking rational worldviews that made some sense in today's rapidly changing, secular times, have warmed to this scientific story even more than many science colleagues, some of whom thought we were hardly more than dabbling dilettantes—or as my department chair told me pointedly in the 1980s, "you're misallocating your time and effort." Sagan, who was a valued mentor while encouraging me to research broadly and teach enthusiastically, nonetheless warned me of the precariousness of testing the tolerance of university deadwood who value almost exclusively specialized, disciplinary work.

Academic attitudes haven't changed much during my forty-year passion for cosmic evolution. The ancient and honorable community of scholars is still composed of splitters and lumpers—the former, majority specialists and narrow-minded, who toil daily while advancing science incrementally by discovering myriad facts that bolster the bigger picture; and the latter, minority generalists and wide-eyed, who endeavor to synthesize those facts as integral parts of that bigger picture. Both philosophies of approach are needed, yet there remains an imbalance; the lumpers who seek unification widely respect the splitters who regularly strengthen their many varied disciplines, yet the converse seems seldom the case, especially in research universities where specialists dominate in numbers, grantsmanship, and perceived value. When will interdisciplinarity become more than a buzzword for central administrators who in principle embrace it yet in practice almost always fail to honor it?

New Tales of Big History

The big historians, too, struggle with interdisciplinarity while their more established history colleagues watch, wait, and lightly probe what's going on. Some compatriots seem interested in the fresh genre of big history and most condone it, yet few eagerly commit. Are these traditional scholars myopic, lazy, or jealous—or perhaps merely judging it a waste of time?

On the contrary, there's no time to waste. Along comes, this year, big history's first textbook, *Big History: Between Nothing and Everything* (2013). And what a marvelous explication it is by Christian, Brown, and Benjamin. As befitting such experienced authors, the book is mostly well written, organized, and packaged. The writing style is inviting—not too pedantic, yet not too breezy, rather just right for innovative courses at the college/high school interface. Each chapter begins with a set of learning goals (posed as questions), bold-faced key terms are found throughout, and the illustrations are colorfully rendered; a brief summary and a few more questions complete each chapter, although the book would have benefitted from more end-of-chapter pedagogical materials. Overall, it's a credible first edition, and I recommend it.

Having published a similar textbook some twenty-five years ago (yet emphasizing ancient times at the front of the story), and now as an experienced co-author of a widely used text in astronomy, I predict, sadly, that this new big history text will not likely be amply adopted. At the college level, as griped above, universities don't much value silo-bursting of insular, sometimes archaic research disciplines, and traditional history departments, will be loath to teach this novel subject since they didn't launch it; at pre-college levels, the text doesn't make clear how it aligns with national standards. I hope that I'm proven wrong.

This new textbook undeniably emphasizes humanity, thus raising again the charge of anthropocentrism. It resembles the pacing of the non-linear temporal treatment in one of the above-mentioned films, heavily weighting humans and their cultural achievements; ten chapters address 0.05% of the full big history story, while only three chapters address the story's other 99.95% (whose coverage of galaxies, stars, and planets would have benefited from a

critical review by an astute physical scientist, thus avoiding dozens of minor errors). This extreme imbalance is perhaps natural for any big history account, but it needs to be fully recognized; humankind does greatly dominate their exemplum.

These skilled authors rightly note that most organized systems display increases in complexity over the course of time, and that it's probably energy flows within those systems that cause the observed rise of complexity. All complex systems—from twirling galaxies and shining stars to buzzing bees and redwood trees—do seem to function optimally within certain boundary conditions, and not surprisingly also have optimal ranges of energy flows. Quantitative studies of cosmic evolution have shown that the vast majority of normalized energy flows for biological systems (including all plants and animals) fit neatly between simpler physical systems (like stars and galaxies) that utilize lesser values of energy (density) and more advanced cultural systems (society and its machines) that have higher such values. I am honored that these big historians have used some of my research regarding ranked system complexity as a main theme of their new textbook. Even so, literary annoyances occasionally muddy the description of major phenomena, notably the central role played by energy in fostering changes that select and reject complex systems embedding the big history story. For example, energy optimality is a process that seems favored throughout nature—an empirical finding that I've championed for many years in numerous peer-reviewed publications (see: 2004, 2011a, 2011b)—not too little as to starve a system, yet not too much as to destroy it. Yet here is where I differ from the big historians, for they (including these pioneering textbook authors) seem inclined to reappropriate such key optimization concepts under the wobbly guise of "Goldilocks conditions" or "Goldilocks circumstances." Alas, there is no need to re-label the well-principled, scientifically based concept of energy-optimization by appealing to humanistically inspired fairytales.

Boundary conditions that are not too hot and not too cold, or physical dynamics that are neither too fast nor too slow, etc., but are rather "just right" to create and sustain complex systems, are synonymous with optimal energy ranges (also just right) that have long been employed by natural scientists. To give but one glaring example, some astronomers a few decades ago cast Earth's habitability in terms of Southey's dreamy Goldilocks fable—if Earth were nearer to or farther from the Sun, or if our atmosphere were thicker or thinner, or if it were abundant in this or that element, then Earth might be unsuitable for life. Shapley had originally called them "liquid water belts," planetologists now term them "habitable zones," yet some colleagues, hoping to bolster sales of books, felt the need to vulgarize. (Social media are also often implicated, such as when they recently and repeatedly softened the science regarding the discovery of the elusive Higgs elementary particle by tactlessly calling it the "God particle," which in turn stems from another author's botched attempt to title his book *The Goddamn Particle*.) Goldilocks-laden descriptions of systems are hardly more than cute restatements that only certain amounts of energy are available to those systems, and that if conditions were different we might not be here. Environmental conditions per se are not an underlying reason for complexification; energy flows through systems likely are; energy is the

cause, complexity the effect.

If big historians are to make headway, indeed to be accepted by traditional historians let alone natural scientists, they ought to ground their research scholarship in scientifically tested ideas and empirically derived results, where possible, and focus their story on the role of humanity in the one and only universe we know. Triple-distilling good, solid science will only unduly dilute the otherwise powerful narrative that big history has to offer. Why must big historians reinvent soft terms that invoke myth or fantasy, yet which cheapen the hard science describing real and complex systems observed all along the arrow of time?

Contention in the Ranks

Confusion and misinterpretation often arise when carefully composed journal articles go unread amid today's harried world of hasty e-mails, biased internet blogs, and un-refereed papers posted on open-access outlets. Needless anxieties also surface when scientists write for non-science audiences (and likely conversely)—and my experiences with big historians are no different. Natural scientists often cringe at many of the qualitative assertions of humanistic and social scholars, while big historians often find daunting the quantitative propensity of modern science. As noted above, a prominent commonality among all complex systems is that energy always seems involved in any transaction that causes change; the origin, maintenance, evolution, and fate of all systems are infused with energy. No unambiguous evidence exists for any event in nature occurring spontaneously, alone, or without energy exchange; energy of some type, at some level, and for some time assures the viability of all physical, biological, and cultural systems. If fusing stars had no energy flows within them, they would collapse; if plants did not photosynthesize sunlight, they would shrivel up and die; if humans stopped eating, we too would perish. Energy's central role is also widely recognized in cultural systems such as a city's inward flow of food and resources amidst its outward flow of products and wastes; indeed, energy is vital to today's economy, technology, and civilization. All complex systems—alive or not—are open, organized, non-equilibrated structures that acquire, store, and utilize energy. Whether stars, species or societies, a unifying trend seems to link (and rank) all such ordered systems in a consistent, uniform manner. That is the true forte of cosmic evolution: Demonstrating quantitatively how everything is related to everything else even within a messy, imperfect universe.

Yet, when big historians chronicle humanity and its cultural inventions, they sometimes depart literally from the storyline—they start telling another story. Some big historians are skeptical about pursuing cosmic evolution into the realm of worldly culture, claiming that the nature of complexity for human society and its built machines differs fundamentally from that of other systems in the universe. They draw a subjective distinction between naturally evolving complexity and human-made "artificial" complexity, arguing that the former appears spontaneously (but it does not) whereas the latter is constructed by us and thus different (yet

artificiality, like intentionality or directionality, are irrelevant in evolution). Is this merely anthropocentrism once more rearing its ugly head, hubristically placing ourselves yet again on a platform, a pedestal, or even alas at the apex of the natural world? Or might this be another case, much like Goethe's devil dressed in the gown of the scholar Faust who prefers to invent new ideas by creating new words, of some big historians opting to divide rather than unify?

In contrast, I have always maintained that we too are a part of nature, not apart from it; schemes that regard humankind outside of nature, or worse atop nature, are misguided. If we are to articulate a unified worldview for all known complex systems, then we must objectively and consistently model each of them identically. Complex systems likely differ fundamentally not in kind, but only in degree—i.e., degree of complexity manifesting ontological continuity. The critics' main anxiety is that cultural complexity often numerically (i.e., energetically) exceeds that of humankind, and they are apparently unable or unwilling to accept that some culturally invented gadgets might be more complicated than our biological selves. However, technological devices were not built by nature without intelligent beings, so it's not unreasonable that some cultural systems' complexity can sometimes transcend those of biological systems, just as life forms outrank simpler physical systems. Perhaps, to embellish Pasteur of yesteryear, chance and necessity do favor the prepared mind.

Cultural evolution is a product of biological evolution, the former building upon the achievements of the latter. Provenance counts; networks of bodies and brains within the human web assemble elaborate contraptions. And it is the rapid pace of cultural evolution, in addition to its ability to harness energy intensely, that makes cultural systems so remarkable. Accordingly, I expect many cultural products to be typically more complex, naturally so, than the biological systems that produce them. I am also comfortable with the empirical finding that some cultural systems, notably machines, computers, and cities that help in numerous ways to improve our health, wealth, and security are likely more complex than we are; jet aircraft operating in three-dimensions and computing extremely rapidly may well be a hundred times more complex than an actively thinking mammalian organism, as their energy-derived data imply. After all, it is the intricacies of our human brains and social networks that have made machines possible, so why should any machine—including vacuum cleaners and lawn mowers—be less complex or have, by design, smaller concentrated energy flows? Try gliding off a cliff with your body, mowing a lawn or vacuuming a carpet with your brain, or even beating an iPhone at checkers; machines perform functions that biota cannot, often impressively so, and more rapidly too. Function also counts; flying high and computing fast are qualities that humans do not possess.

This is not to say that cultural systems are smarter than we are; no claim links our complexity metric with intelligence, rather only cultural systems are arguably more intricate, complicated. For big historians to declare that sentient, technological society is not analyzable in the same way as stars, galaxies, and life itself is tantamount to placing ourselves in some special category or atop some exalted pillar, raising the age-old specter of mystical

rulers and arrogant institutions. It would be as though nature adheres to a universal concordance, creating all known systems in a single, unified, evolutionary way—but only until the big history story reaches us, at which time society and our cultural inventions are alleged to be different, or artificial, or privileged. I reject such teleology, which has so often been detrimental to humankind during much of recorded history. My stance on cosmic evolution very much includes culture and civilization among all natural systems, indeed regards human society and our remarkable technology "on the same page" alongside every type of complex system known in the universe.

Why, in our Copernican-principled day and age, are big historians, much as some biologists and many anthropologists, prone to "split" (hence divide) efforts to "lump" (hence unify) all that we observe in nature, thereby requiring an assorted array of "just-so" stories, much like those of Kipling and his fanciful descriptions for each and every animal in the forest uniquely? I urge caution when professing, egocentrically or for reasons of personal belief, that the complexity of social systems differs in kind from that of any other organized system. There is no objective evidence for humankind's specialness and no need to assert it subjectively.

A Challenge and a Risk

Perhaps the biggest challenge for big historians is that much of their story is decipherable only by scientific means. Virtually all knowledge of what preceded written records (well more than 99.99% of the big history chronicle) derives from the modern scientific method, including everything known about cosmos, Earth, and life. To their credit, many big historians aspire to include the latest scientific findings within their developing narrative—"using the best available empirical evidence and scholarly methods," according to the mission statement of the fledgling International Big History Association (ibhanet.org)—yet so many of them falter when computing, interpreting, or merely using numerical quantities.

Admittedly, some of the technical afflictions of big historians stem from poor presentations by scientists (including perhaps some of my own arduous journal papers). An example is a relatively recent book on energy and society that is widely referenced by big historians, yet which has caused untold confusion by calling the very same energy-flow term noted above by at least six different names with six different units—the kind of incoherent scientific writing that often serves to "keep the beginners out" by creating frustration among non-scientists seriously trying to embrace science and technology in the course of their scholarly research. We scientists need to communicate better our subject matter with those not trained in it, yet our present science culture fails to honor such talents.

It does seem these days that everyone wants to be a scientist. I recently introduced an undergrad to a colleague as one who studies economics, but she scolded me by exclaiming that her discipline is "economic science." A dean, who is a political scientist, blurted out defensively in my office last month, "I'm a scientist too, you know." Behavioral science,

sports science, library science, exercise science, psychological science, creation science; even guys who pick up trash by the roadside in my hometown, once called garbage collectors and then sanitary engineers, are now officially entitled sanitary scientists. I've always been puzzled why social scholars are so insecure about their subject being called, as it once was, social studies, demanding instead that it be rebranded as social science when they know full well that society is so complex as to make virtually impossible controlled experiments like those done by natural scientists. Social scholars should be proud of their research, without trying to repackage it as science; given the plethora of grave issues facing humanity today, social studies might be more relevant for our survival than the natural sciences.

In all fairness, I—an experimental physicist by training and empirical materialist by philosophical bent—also find troubling much of what passes for frontier physics today—string theory, superstrings, supersymmetry, multiple universes, eleven dimensions, none of which has even a shred of evidence to support it. A unified understanding of nature need not postulate metaphysical schemes in abstract cosmology or untestable ideas in theoretical physics. A coherent, phenomenological explication of what is actually observed in our singular, four-dimensional universe populated mainly with galaxies, stars, planets, and life comprises a useful advance in comprehending, and to some extent unifying, the extended, diverse world around us. Besides, would any intelligent person actually be willing to cross a bridge or fly in an aircraft built on the untested ideas of 11-dimensional string theory?

The risk to big history is that its followers, unable to distinguish between real science and pseudo-science, are occasionally fooled by the latter—if only because junk science is often easier to grasp, slickly presented, or matches personal persuasions. Today's society is laden with charlatans propagating idiosyncratic beliefs, fringe elements, and wacky ideas that have absolutely no basis in science or even in logic and rationality. In the interest of inclusiveness (a good goal), big historians seem inclined to embrace all sorts of alternative worldviews that often amount to hardly more than subjective fluff run amuck (a bad outcome). The only big history meeting that I've attended to date, in Moscow two years ago, was abundant in such New Age claptrap, with my own paper on energy-rich technological society surrounded by talks on global spirituality, evangelical religious cures, life extension techniques, and synthetic body-vessels for the mind (causing another scientist, also scheduled for the same session, to withdraw when he realized what was happening). Tension does persist among big historians and natural scientists, not from interpreting the big-bang-to-humankind story per se (for there's much agreement among major narrators), rather from its basic facts and figures clashing with perceived meanings and intentions—the former I can handle, the latter I cannot. Why do so many big history advocates associate natural events with "purpose," "progress," "magic," and "meaning," all of which slippery words are anathema to most physicists who feel they do not aid objective understanding of our material universe? It's always dangerous when big historians jet about the country proclaiming that their new-found subject grants them the meaning of life—only to be struck mute when asked to articulate that meaning. Perhaps the hype is mere overt enthusiasm, as with scientists Watson and Crick,

who, having discovered the structure of DNA more than a half-century ago in the real Cambridge, ran straightaway to the local pub to buy a round of drinks—and to announce they had found life's meaning; yet, when they couldn't explain it, they consoled themselves (and everyone else present) by buying another round. Let's hope, paraphrasing one of the Huxleys, that the slaying of a beautiful story by an exaggerated claim does not become big history's greatest tragedy.

Will big history rise to the challenge of genuinely embracing modern science's central dogma, thereby accepting the need to test ideas while soundly rejecting those that go untested—or will big history fall prey to the risk of alienating the natural sciences that undergird its very own essence, all the while becoming the latest entry in a long line of learned ponderers struggling up the mountain to fathom who we are and whence we came? Which will big history become when it grows up: A bright and shining light in the otherwise dark firmament of mysticism, or another mythical contributor to that very same dim and dreaded darkness?

The Promise of Big History

Big history is not a recounting of imagined fables, magical powers, or belief-based accounts of our origin and evolution. In demonstrable contrast, this ambitious enterprise nobly aims to chronicle natural history writ large, from big bang to humankind, without assuaging potentially the grandest of all narratives with equivocal terms and fictitious notions that sow doubt and misconception, yet skirt serious understanding of how material systems emerge, mature, and terminate. If big historians are to base their awe-inspiring, interdisciplinary story on the empirical evidence of modern science, then they ought to accept some objective, quantitative reasoning without recourse to pseudo-scientific nonsense and without pandering to those clinging to antiquated subjectivity; linguistic distortions intended to soften hard science and renewed calls to place humankind on a culminating pedestal will likely lead to qualitative confusion and needless controversy—ultimately to the detriment of what is perhaps the greatest story ever (to be) told. I for one, and despite the slightly intemperate tone of this essay, surely do hope that big history spearheads a novel methodology that goes well beyond the lofty words of poetry and superficiality of metaphor, thus becoming a profound interdiscipline that genuinely transcends academic barriers and provides an exciting new way to view ourselves and our world in our richly endowed universe.

Works Cited

Chaisson, Eric. 2004. "Complexity: An Energetics Agenda. Energy as a Motor of Evolution." *Complexity* 9.3: 14–21.

——. 2011a “Energy Rate Density as a Complexity Metric and Evolutionary Driver.” *Complexity* 16.3: 27–40.

——. 2011b. “Energy Rate Density. II. Probing Further a New Complexity Metric.” *Complexity* 17.1:44–63.

Christian, David. 2005. *Maps of Time: An Introduction to Big History*. Berkeley: University of California Press.

Christian, David, Cynthia Stokes Brown, and Craig Benjamin. 2013. *Big History: Between Nothing and Everything*. Princeton: McGraw-Hill.

Spier, Fred. 2011. *Big History and the Future of Humanity*. Chichester, West Sussex, UK: Wiley-Blackwell.