

# *Integrating Freshman STEM Education into a Big-History Course in Japan*

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Citation | Robert, Martin .(2023) Integrating Freshman STEM Education into a Big-History Course in Japan. *Journal of Big History*, VI(1); 73–78.

DOI | <https://doi.org/10.22339/jbh.v6i1.6109>

Undergraduate education for Science, Technology, Engineering and Mathematics (STEM) has been a global priority of governments for decades, because of its direct connection to work-force development in a world with growing dependence on technology and information. Technology is the outcome of an evolutionary process leading to increases of complexity and emergence of new functionalities, which is a central theme in Big History. In modern Japan, large public universities focus on undergraduate STEM education, originally inspired by the American model. This Japanese STEM approach is rather heavily based on liberal arts and general education courses that are taught as distinct silos in mathematics, physics, chemistry, biology, etc. At least, this is the case for most of the first-year and some of the second-year content in most four-year degree programs. This model has its benefits and provides a solid foundation in these disciplines, one that expands on high school experience. However, this often means that students tend to overlook or forget the deep connections between disciplines.

Most students are eager to go on to the more advanced courses in their chosen program. Such specialization is understandable and desirable, but understanding how it emerges and why it can work in a larger context of differentiation, connections, exchanges and self-organized complexity is an important message to convey to the budding scientist / engineer. The first year of general-science education seems to be an ideal moment at which to provide an opportunity to look more deeply into these critical connections.

I was faculty at Tohoku University, a top national research university in Sendai, north-eastern Japan. In 2013, I was asked to teach a course on ‘Life and Nature,’ a requirement for international students studying in English at our Future Global Leadership Program. The majority of students came from South Asia and East Asia to study in specific STEM programs – 1) Marine biology, 2) Molecular chemistry, and 3) Aerospace / mechanical engineering. ‘Life and Nature’ was meant to provide a good, general education STEM component in preparation for more advanced studies.

## *Evolution of the Course*

Fortunately, I was given much freedom regarding the orientation of the course content. The ‘Life and Nature’ course title inspired me, in 2013, to connect fundamental principles of biology to their roots in the inorganic world and the cosmos. Indeed, I saw how an integrated STEM experience is more about what lies between different forms of complexity than about the complexity itself.

Early in my career, I had become fascinated with the concept of emergence, a process that had deepened my own research interests on the biochemical analysis of bacterial metabolism. This led me to study cell-cell interactions in bacterial populations. From there, it was a small step to appreciate how all major steps in evolution are based on increasing interactions between otherwise similar elements. It was this narrative of elements coming together, mediated by physical / chemical forces, to bring new complexity into being that I was hoping to instill in my students.

Of course, this complex process needed to be simplified for ‘Life and Nature.’ I had to distil away many of the details about the elements themselves and focus instead on the process. I thought that the freshman level was an ideal time to do this, considering the liberal arts emphasis on basic knowledge. I was hoping to offer a way for students to better connect the basic mathematics, physics, chemistry and biology they were learning and bring them more satisfaction along the way.

Little by little, this blending of life, cell biology, earth science and ecology grew into something more, as I dug into the underlying principles of physics and cosmology. At that point, there seemed to be no other logical starting point than the Big Bang. But teaching these additional themes was unsettling for me as a biochemist! Then, in 2015, by chance, I watched David Christian’s inspiring Ted Talk, ‘The History of our World in 18 Minutes.’ As a result, I learned about the Big History Project that Christian had developed with Microsoft Research and realized that this was a resource that matched my ambitions to introduce concepts of complexity science in an accessible way. Big History brought together a mixture of content that fulfilled

our curriculum expectations and helped students connect the disparate and individual silos of disciplines they were learning. Much of the desirable material outside the scope of my original course could now be accessed freely from the Big History Project website.<sup>1</sup>

Such courses had been taught at universities around the world for some time, but, in Japan, Big History remained relatively unknown. I taught my revised course for the first time in the Fall of 2015 as ‘Big History: The Organization and Evolution of the Universe (From the Big Bang to Now)’. It was the first such course in English at the university level in Japan.<sup>2</sup>

Following its development, I was asked to participate in a multi-instructor course at Tohoku University also based on big-history concepts – ‘Big History: Connecting Natural Science to Society.’ It aimed to engage a freshman Japanese student audience as an elective offered to first-year students, regardless of program. It was more focused on Earth sciences, astrobiology, the origin of life, evolution, natural selection, and human history. As such, it had a different ambition with a different set of trade-offs, providing more depth but less breadth than the English-language course on which this article is focused.

### **Strategy and Objectives**

The Big History Project was originally developed for middle and high-school students, but I rarely, if ever, felt that the content was underwhelming for our university students. Its relative simplicity but elegant focus on connections was ideal. For the students, many studied in English for the first time, so a less-challenging content was advantageous as they adjusted to Japan and a heavy curriculum. Most of their videos and documents were well designed.

The course was brief, considering the material covered – fourteen weeks of 90-minute classes. Covering Big History in such a limited time obviously comes at a cost. The course focused on the first five units of the Big History Project for eleven weeks, covering cosmology, earth, the origin and evolution of life, ecological balance, and the scientific foundations of this knowledge. It then went more quickly through the next five units in only three weeks about early humans, agriculture, expansion, acceleration, and the future.

The Big History Project lacked some content in areas I was hoping to explore, so I added content on biology and ecology for the Life unit, which was prominent in my course. I also added new data about physics, forces and particles, inspired by astrophysicist Eric Chaisson’s website on Cosmic Evolution (2013).<sup>3</sup> With reluctance, I reduced the

content about human development, due to our semester’s time constraints and focused on the STEM part of the Big History Project. I hoped that students, regardless of their origin, had learned enough of that in high school and could extrapolate their knowledge.

The choice of a single-instructor model for such vast and diverse content resulted in significant challenges, but I thought it would enable me to maintain a well-integrated structure along with smoothly linked methods and activities. I also could more easily highlight connections between the different units. There were challenges, given that my expertise is in biochemistry and microbiology, but my scientific training and broad interests allowed me to successfully achieve my ambitions.

With a class size of about twenty-five to thirty-five students, I opted for an evaluation model in five different categories – attendance, homework, in-class work, a project, and a final examination. This helped relieve the pressure common in final-exam-based evaluation systems common to STEM. It also facilitated progressive and constant effort. Assignments and in-class activities included questions from the Big History Project related to videos or written documents on their platform. This allowed me to confirm whether students used the material and understood its content. Many open-ended questions were used for in-class discussions in groups of three to five students. Answers were often reviewed live and shared with the whole class. The main objective of the project, done in pairs, was for students to choose a topic relevant to Big History on which to further elaborate. The final examination contained a series of multiple-choice questions, as well as some development type questions, with more focused or open-ended questions to verify that they understood key concepts for each unit.

### **Results: 2015–2019**

A central goal was to provide students with an overview of the physical and natural processes of the last 13.7 billion years, which led to the world that surrounds us today, especially the fantastic growth in complexity. My ambition was to help students from various fields appreciate the interdependence between physical, chemical, biological, and social sciences. While I won’t present empirical evidence about course outcomes, I will share some students’ comments about the course:

*Learning Big History throughout this semester was new and interesting topic for me. It’s such a great course overall but please cut the amount of homework.*

*BHP is a very great resource. I really like Life and Nature as it showed me the world in a new perspective.*

*There are so many assignments and projects even it is just the general class.*

*I don't see its usefulness to engineering students. Rather one more physics or math class would have been more useful.*

Many felt a final exam was unnecessary, but I saw it as a healthy part of individual assessment. Overall, students thought that the content was too vast! I responded that – obviously – it is, but each component has relatively little depth, so the amount of information is similar to any other course. The major gain is in making sense of things rather than just information or facts acquisition.

Some reported that they felt little connection to their future specialized programs in marine biology, molecular chemistry, or aerospace / mechanical engineering. I explained that a better ability to see connections will help them downstream in their careers. I may have been only partially successful at convincing them.

Many of the student comments reflect the very trade-offs made in teaching big-history – captivating but overwhelming at the same time ... providing many answers while leaving some explanations ambiguous. I'm hopeful that by adjusting some of the content and activities to reduce pressure on students, the majority would count it as a positive learning experience.

### **Benefits / Critiques of Big History**

I believe the power of using Big History in STEM education is in how it allows students to connect disciplines at a moment when they begin to study each of them in a deeply focused but disconnected way. The single most important theme of Big History is the growth in complexity exemplified in the eight-threshold vision of the Big History Project. These allow us to make sense of much of the natural world that surrounds us and integrate those disciplines. Occam's razor comes in handy too, doing away with some details that obscure the simple.

From the interactions of a small number of elements and forces that emerged early in the history of the universe, amazing complexity has emerged. This is the powerful message that is both inspiring and reassuring in its power to explain the emergence of complex, living organisms. Big History is really a story about complex systems, a repeat-

ing pattern of coming together at different spatial-temporal scales, where emergence takes the central stage and leads to us humans and to what lies ahead. Simple, understandable, flexible, expandable and comforting in what otherwise can look like an incomprehensible, tangled mesh of details.

While many details of the origin of the universe and the origin of life continue to be debated at length when our knowledge is short, the growth of complexity by successive steps of assembly is not. This is a central process in the evolution of the universe. Destruction and reconstruction are also part of the scenario, from stars and planets to cells and metabolism and our own societies. Rebuilding is a crucial process for continuation of evolution over time.

In spite of all its appeal, Big History has also been the subject of criticism. It's mass appeal seems to leave historian Ian Hesketh wondering about important missing parts in the narrative:

What this means is that Big History necessarily privileges the cosmic at the expense of the human, the natural at the expense of the political.<sup>4</sup>

It seems that Hesketh misses the point. Even traditional human history hides complex dynamics that we are still uncovering, and, in so far as it is based on written records that survived by chance, it also introduces significant biases. Certainly, the complexities of our modern world cannot be reduced to natural events predating human history, but this was never the idea behind Big History. As David Christian described, not satisfied with his knowledge of the history of one country, he needed to explore the history of the world, which ultimately led to an additional need to explain earlier events, such as the origin of humans, life and other events, ultimately all the way back to the Big Bang. But the goal was not to explain everything.<sup>5</sup>

History records events over time, so it requires a beginning. The Big Bang represents the very emergence of space-time and is therefore the ultimate starting point, while acknowledging that the subject is debated and that there are alternative models. At the same time, Big History seeks to provide a unifying narrative leading to humanity's emergence. Beyond these points, we see that human history is not unlike the natural history described in Big History – a small number of elements coming together in larger numbers, where more is different, differentiating and developing mutual dependences and interactions. The narrative is rather similar.

This, I think, is where the power of Big History lies – in showing us that the same process occurs at all scales in

both the living and non-living worlds. It can take us from a hot plasma of particles to our interconnected socio-biosphere in an incessant energy-driven process of assembly and reconstruction. While some criticism is warranted and healthy, the simplified but unified view of Big History is where its power resides.

Hesketh's criticism also identifies Big History's ambition to fill the gap left by secularization in society. The message of Big History is satisfying in the sense that it provides a framework to connect areas of knowledge that appear disparate. He also resents the lack of details about Goldilocks conditions that are used in the big-history narrative. While at times unclear, Goldilocks conditions highlight the importance of suitable environmental conditions that act as selecting agents in an evolutionary process that, while different from a biological one, follows a fundamentally common mechanism. Hesketh adds:

This speaks to the difficulty of integrating a sense of human agency into the Big History narrative, a problem that becomes particularly important at the end of the story. ... Humans are passive observers to the major developments of the period we are supposedly shaping.

While there may be some truth to his assertion that Big History is privileging the cosmic at the expense of the human and the natural at the expense of the political, I was not preoccupied by this issue in my STEM course but was more focused on the events leading to origins of humans. Hesketh argues for more human agency to be injected into the big-history narrative, which I think is a good point but is less problematic for early thresholds. The human development part may be more challenging, since many of its complexities are ignored, but these include many cultural and political biases.

Big History has been criticized for 'dehumanizing' history, a judgment that may come from a narrow reading of just human history. David Christian meant to use history as a track-record of events, whether before or after the emergence of humans. In that sense, it does not need to be in conflict with history but rather it is an extension of natural history.<sup>6</sup>

Understanding the major events that led to human emergence is a necessity for human history, and so it is that which really distinguishes Big History. Eric Chaisson shows that when the nearly 5-billion-year history of our planet is scaled to a 50-year duration, all of recorded human history represents only the last half-hour.<sup>7</sup> So the appeal of explor-

ing and making sense even in a superficial way of the major natural events leading to us does not appear misguided.

For me, focusing on scientific content was both an objective (for a freshman STEM course) and a necessity (time and an expertise shortage). In that sense, the course I developed, while based on Big History, could easily do away with 'Big History' in its name and be called simply 'Evolution of the Universe,' as in the course subtitle. There are gaps in the big-history narrative that I have tried to fill to some extent, but these choices were subjective.

These additions include my additional introductory content on forces, particle physics, the standard model, the origin of life and biology/ecology. On the other hand, I reduced the parts about human development while keeping the critical role of the development of symbolic language and agriculture in terms of solidifying the themes of interactions, energy harvesting, and the immense growth in human complexity. Finally, briefly introducing the modern energy revolution was important to the introduction of technology and its expansion while other elements appeared dispensable from the STEM perspective of the course. I also tried to introduce the versatile concept of energy-rate density as an observable calculation, whose values grows as our universe increases in complexity.<sup>8</sup>

Addressing some of the criticism about Big History might be as simple as just clarifying the big-history objectives that vary from human history. More depth is not necessarily a solution. Depth can be easily outsourced. Perhaps, the links and references to external and highly curated resources just need to be reinforced. Big History must remain, in its fashion, a quick-user guide to our universe, one that indexes details when needed. This, I think, is its main appeal.

For STEM courses, improvements could also include more developed scientific content for each unit and expansion of the mini-thresholds of life. They may appear smaller in scale, but innovations like photosynthesis, the emergence of eukaryotes, evolution of multicellularity, animals moving from the sea to the surface and mammal development all had massive repercussions for life that warrant a closer look into driving forces and mechanisms.

### ***A Universal Appeal for STEM Education?***

The theme of Big History has universal appeal for students, especially in STEM. A narrative based on knowledge collected from scientific evidence should have such appeal. At the same time, language reflects culture – course content limited to resources in English obviously entails limitations. Students from East-Asian cultures may be more familiar with themes of interconnectivity and interdependence that



shape the big-history narrative. On the other hand, Japanese students often can be hesitant to express opinions publicly. A test-taker mindset common in Asia can confuse some students when the emphasis and evaluation of a course is more diversified, and at times open-ended. These cultural nuances are thus all factors to keep in mind.

Early on, the Big History Project confronts varied cultural traditions in its origin-stories component, which offers a good chance to identify similarities and differences across the world. Many of these we can connect to topics in evolution. Although their human-development component neglects many cultures around the world and is biased toward a Western view, there are efforts to profile important events and historical figures in other cultures. On top of that, natural and human-made conflicts that led to the destruction of important sources also introduce its users to additional biases. However, for the STEM focus I chose, the ramifications of these events are more limited.

Big History provides a view of what unites all humans and cultures rather than what differentiates them.<sup>9</sup> This universal appeal can be adapted to all levels of education and is suited for all cultures. Its focus on the growth of complexity through similar processes at different levels is at its core. Specific content and attention to mathematical understanding is where there is freedom to adjust the educational level. There are many things that can be improved on in the course I decided to teach, such as more discussions, debates, and research-oriented activities.

Physicist and Nobel Laureate Philip Anderson rightfully pointed out in 1972 that ‘More is different .... Biology is not applied chemistry and psychology is not applied biology.’<sup>10</sup> Anderson was describing emergence and the role of complexity at all levels of organization and the difficulties faced by reductionist approaches. In a sense, this is also the main message of Big History. As our universe organizes and evolves into systems with increasing number of elements, it becomes different, it gains new properties that make completely new and different things possible.

I think that, by providing evidence and examples of key events that reaffirm our dependence on each other and on the natural world, and by highlighting the deep connections between all evolutionary steps in the universe’s history, the narrative of Big History seems to encapsulate the essence of what one should know as a person, at least from a STEM perspective.

### **Closing**

The elegance of the big-history and cosmic-evolution narrative is that it describes growth of complexity as an inti-

mate coming together of similar elements, at all scales from the subatomic level to ourselves. Humans and our emerging global societies pass through molecular and biological evolution. The forces that catalyse the process take on different forms but ultimately serve a similar objective of assembly making possible a remarkable growth in complexity. Some singularity events like the origin of the universe and the origin of life remain to be better understood, but, overall, the scheme makes sense in a way that is satisfying for young enquiring minds.

Whether our universe is headed for a heat-death or a new beginning remains an open question for which the big-history narrative has no answer, and that is its very essence. I hope that Big History or similar forms of integrative and transdisciplinary education will continue to grow in popularity, in Japan, in Asia, and the rest of the world. As a key learning instrument, it can help students make sense of the multiple disciplines they are trying to master individually, make them better able to see and appreciate the essential connections between them, and what it means for us, our past, present, and future.

Martin Robert’s supplementary big-history course material: <[https://drive.google.com/drive/folders/1ndMFg6aS-3sO7BiG\\_U-B6MmVO01OM3vS\\_?usp=sharing](https://drive.google.com/drive/folders/1ndMFg6aS-3sO7BiG_U-B6MmVO01OM3vS_?usp=sharing)>.

Acknowledgements: The author is grateful to Norihiro Nakamura, Yumiko Watanabe, Mitsuru Haga and Takeshi Koike at Tohoku University for discussions about Big History and for sharing some teaching material and ideas. The author also greatly appreciates the support and suggestions of Barry Rodrigue (Symbiosis School of Liberal Arts) and Nobuo Tsujimura (Asian Big History Association) and their help with the manuscript throughout the publication process.

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## Endnotes

1. Big History has rapidly gained global attention from its origins in universal history and cosmic evolution. David Christian coined the term 'Big History' over thirty years ago. In 2011, he and his colleagues launched the Big History Project as a freely accessible set of online resources. They focused on secondary students in the United States, Australia and the Netherlands, but their model and materials also spread independently to other educational levels around the world. Rodrigue 2022. Christian 1991. Big History Project c. 2022.
2. Historically, there have been independent efforts to teach big-history concepts in Japan, some as early as the late 19<sup>th</sup> century and some more focused on the modern big-history narrative in the 2000s. From 2013, academics from Soka University and J.F. Oberlin University started to collaborate on a project that resulted in Oberlin's Big History Movement and their course on 'Understanding Nature (Big History)' in 2016. It also led to the founding of the Asian Big History Association in 2014. Nobuo Tsujimura, personal communication, 2022, Tokyo. Rodrigue 2022.
3. Chaisson 2013.
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