Beyond CO_2: Exploring the Complexities of Climate Education

Young people will need a nuanced climate education to tackle the climate challenges of tomorrow. This involves teaching climate science and policy in a way that is action-focused, personally relevant, and scientifically rigorous. To achieve these goals for climate education, it is necessary to establish a broad framework for understanding and thinking about climate science. This piece will focus on teaching about a subset of scientific practices used to understand climate, aiming to help people shift to viewing climate in more expansive ways and potentially to resolve issues regarding doubt about the scientific consensus.

Currently, there is a substantial body of research regarding climate science and policy, much of which is unfamiliar to the public. Climate.gov provides a list of "essential principles" for climate literacy, which can be used as a starting point or reference for developing climate curricula—yet there will always be foreseeable room for more nuance. To be most effective, climate education should provide students with a framework for exploring issues surrounding climate by themselves, and this involves knowing how to defend as well as question claims regarding climate science and the efficacy of climate policies—in other words, answering, "What exactly does the science *say*?" This goal can be supported by teaching students to understand patterns cutting across complex systems such as climate.

Understanding How Climate Works

Many people have heard that CO_2 causes global warming, but the mechanism by which this happens is not clearly understood. After all, the atmosphere is a giant system, and there is a dauntingly innumerable number of "feedback loops"—processes that speed up or slow down changes in Earth's climate. Given the complexity of the climate system, how can we conceptualize how it works? We can consider two broad categories of approaches: a "bottom-up" approach and a "top-down" approach.

Until recently, bottom-up approaches have been more popular. It makes sense that this is the case—it's more tractable to understand climate through individual feedback mechanisms in smaller subsystems than to look at the entire climate system. For instance, we might look at climate science through the lens of fluid dynamics, asking questions about the hydrologic cycle and how it affects climate sensitivity.

However, it is becoming increasingly evident that a top-down approach can also be incredibly effective for understanding climate change. We can interpret the climate system as just that—a system—and we can mathematically formalize it as a system evolving over time. Of course, this would not be possible without numerous tools that have been developed over time. Fortunately, geologists have worked to reconstruct the history of Earth's climate from field observations and numerical simulations, resulting in climate models that provide us insight into what Earth's climate was like millions of years ago. Scientists have used these data to understand climate as a complex system exhibiting patterns in its long-term evolution.

There remains the question of how to make this top-down approach tractable. To address this question, one can note that many disparate systems in nature exhibit similar patterns in behavior due to being governed by the same set of simple rules. This is called the phenomenon of *self-similarity* in nature, unifying different systems through common sets of simple canonical equations. One example of self-similarity in nature can be seen in the example of reaction-diffusion equations, which are mathematical models used to describe reacting components. These models are pervasive throughout the natural sciences—describing phenomena ranging from vegetation patterns to tumor spread. Due to the phenomenon of self-similarity, it is often useful to reference empirical laws and patterns observed in other natural systems when studying complex systems such as the Earth's climate.

Examples of patterns arising in nature. Image sources: (L) Tennessee Aquarium, (R) J. von Hardenberg

To find similarities with other systems, we first need to consider what model we want to use to understand the climate system. Since the climate system is incredibly complex, scientists seek for such models to capture the general behavior of the system without needing to consider specific feedback mechanisms. When looking at climate from a big-picture perspective, it is useful to focus on the behavior of important climate system components known as *tipping elements*, identified in previous climate science studies. Tipping elements refer to large-scale regions of the Earth prone to "tipping," or reaching points where they experience abrupt and irreversible shifts in their long-term states. One example is the Greenland ice sheet (GIS), whose melting may have a substantial impact on the state of the Earth system. Because tipping elements are so large in scale, understanding their dynamics can be essential to understanding the possibility for abrupt climate shifts.

Further, much work being done for large-scale physical systems such as the climate system builds off previous work done for smaller-scale systems; the phenomenon of self-similarity in nature makes many of the same principles still applicable. For example, we can think about how to understand the situation where ice loss occurs at different rates throughout the Greenland ice sheet, causing "partial tipping" to occur (for instance, just one specific subregion of the GIS could transition into a different long-term state). It becomes useful to study analogous phenomena that have been studied for smaller-scale Earth subsystems such as savannas, providing insight into the behavior of the larger-scale model. This makes understanding larger-scale problems more tractable, and greater understanding of such problems can help provide new insight into the resilience of the climate system and the risks of anthropogenic change.

Studying the complexity of environmental systems boils down to asking ourselves how we can interpret natural-world data and observations in terms of simple physical systems. Some of the biggest results, like the Lorenz equations for atmospheric convection, turn out to be impressively simple, but at their core is a bedrock of rigorous physical concepts—what are the primary factors governing the evolution of this system? These can be surprisingly difficult to pinpoint. There is great potential for using the top-down approach of systems evolution to understand how Earth's climate changes over time and help us to address such questions: this approach builds on our intuition about patterns we can observe in natural systems and provides a bigger-picture view of how the climate evolves. If one discovers a significant commonality between the climate system and a canonical system that scientists have studied extensively in another context, the climate system (or some aspect of it) could become much easier to analyze. This approach to understanding climate reinforces the major theme of unity in physical and biological systems, enabling climate science to be integrated more easily into existing curricula for the natural sciences.

Next Steps for Educators and Students

It is important for students and teachers to have a multifaceted understanding of climate science. This involves learning about perspectives on climate science and scientific practices as well the personal relevance, implications, and current policies surrounding climate change. Understanding these concepts will help students to be better equipped to bring their skills and interests to help us progress toward climate solutions.

Currently, climate education is more focused on the social scientific aspects of science, but it is important for students to develop skills to understand and critically analyze the latest research in climate science. After all, nothing in real life is as simple as "CO_2 warms the climate." Thus, a key goal of climate science education is to help students develop cause-effect understandings of natural phenomena associated with climate science and to equip them with the skills to make their own judgments of developments in climate science (Ferguson and White, 2023).

As climate concerns continue to grow and related issues become increasingly pressing, the climate leaders of tomorrow should be equipped with skills for thinking about the climate system and frameworks to understand how to approach broad questions about climate, from scientific ones ("How do anthropogenic changes affect climate?," "What will the climate be like in 2050?") to policy-relevant ones ("How do you quantify what climate policies are most relevant or useful?"). Plenty of different factors go into answering such questions, and it's possible to provide new insight into them using unique approaches and insights from distinct subfields.

Looking at the broader picture of climate change, it's important to take a top-down approach toward answering these important questions. Using a systems evolution approach to understand climate will help students to understand systemic complexity through a scientific lens. This approach can also be useful for integrating climate science into curricula for the natural sciences—particularly physics, chemistry, and biology—in a way that supports the broader framework of unity and disorder in natural systems (Dupigny-Giroux, 2010).

There is still substantial progress to be made in climate education, both regarding expanding to more schools and incorporating more content (especially in science). Looking ahead to the future, it will be important to expand our existing climate curricula so that they become more extensive and commonplace in the US education system. Following what educators have already started doing, it will be valuable to continue teaching students about sustainable ways of living and the urgency of the climate crisis in the context of social science. However, improving climate education must involve more interdisciplinary approaches, particularly teaching often neglected aspects of climate science. Within climate science, it is particularly valuable to introduce a top-down systems evolution approach with connections to physics, chemistry, and biology: this approach provides insight into the interconnectedness of natural systems and a quantitative, intuitive framework for understanding climate as a complex system. Furthering climate science education in this way will help to provide a more interdisciplinary backbone for climate change education and help to produce a populace better informed about the complex scientific consensus on climate.

Overall, small steps toward improved climate education start with sharing perspectives on climate, involving personal experiences as well as perspectives on climate from all areas of the natural and social sciences. An important goal of climate education is to equip students with the ability to address the complexity of the climate system and recognize the diversity of perspectives that enrich our understanding of the latest climate issues and developments. Newfound perspectives from the sciences may be the catalyst that inspires, imparts with knowledge, or impassions ordinary people who care about the climate to make strides toward climate solutions.

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