PART 3

Toward (E)quality in Education for Climate Action

Toward a Transdisciplinary, Justice-Centered Pedagogy of Climate Change

Vandana Singh

Abstract

Along with scientific and technical open questions, climate change presents unique epistemological, sociological, psychological, and ethical challenges, including climate justice. These are reflected in the education sector as well, manifesting as roadblocks and barriers at both the macro level and in the microcosm of the classroom. The failure of the education sector to take on the climate challenge is deeply problematic, since effective climate education can be a crucial component of climate mitigation. This chapter presents a re-conceptualization of the climate crisis at the intersection of science, society, ethics, justice, economics, philosophy and history of science that seeks to overcome the above-mentioned barriers. Drawing from a close study of the implementation of this framework in an undergraduate physics classroom for non-science majors over nearly a decade, I articulate four dimensions of an effective pedagogy of climate change: the scientific-technological, the transdisciplinary, the epistemological and the psycho-social. Three transdisciplinary “meta-concepts” constitute the foundation of this approach, utilized in the classroom via repeated use of visual tools. Student responses indicate that this still-developing framework has promise in the classroom and beyond.

Keywords

education for sustainable development – transdisciplinary – climate change – pedagogy – higher education

1 Introduction

The climate crisis presents formidable challenges of transdisciplinarity, complexity, and vast spatial and temporal scales. It is no wonder, then, that modern industrial civilization’s emphasis on short-term, linear thinking, atomism and

reductionism – aspects that are inevitably reflected in the educational mainstream – render us unable to conceptualize, let alone mitigate, climate change and its attendant ills. Climate change is also a crisis of ethics and justice, disproportionately affecting those who are least responsible for it, including the poor, people of color, the Global South, Indigenous people, and the young. Justice is therefore central to the social-ecological complex of crises that includes, and is exacerbated by, climate change (Levy & Patz, 2015; Robinson, 2019). Indeed, it has been pointed out that a sustainable future is not possible without social justice and equity (IPCC, 2018).

This chapter describes one educator's journey toward a transdisciplinary, justice-centered framework for teaching climate change, developed in a general physics college classroom in response to the above challenges, over a period of nearly a decade. My first, naïve assumption that teaching climate science fundamentals in a physics class would help my students prepare for an uncertain planetary future proved incorrect. Students reacted with disbelief, anger, despair, hopelessness, and apathy. Nor were they able to engage with the material at the cognitive level to my satisfaction. These early failures made me realize that teaching climate science in isolation from other concerns was not only insufficient, but deeply problematic. A trip to the Alaskan North Shore in 2014 to design an interdisciplinary case study on climate change for undergraduate education (Singh, 2015) furthered my conviction that transdisciplinarity was crucial, and the issue of justice, central.

2 Roadblocks and Barriers to Effective Climate Education

In the context of education, five roadblocks at the macro level have been identified in the path toward effective education for sustainable development (Kwauk, 2020). These are: the secondary status of eco-literacy; the lack of a radical vision for climate education; issues of definition and scope regarding education for sustainable development (ESD); limitations of monitoring and accountability mechanisms; and the lack of systemic support for teachers to become change agents for sustainability.

In the microcosm of my classroom, these roadblocks manifest in the form of five kinds of barriers.

2.1 *Knowledge Pollution and Ignorance*

Students' prior knowledge, thoughts, and feelings about climate change often mirror public confusion and misconceptions about the issue. Most students have not had a solid grounding in climate change fundamentals in high school.

2.2 *Transdisciplinarity*

The problem of climate change has multiple ramifications: economic, historical, and sociological, including issues of justice, among others. In our siloed (that is, compartmentalized) education system, disciplines have developed their own paradigms, approaches, concepts, and terminology. Neither students nor teachers are trained in transdisciplinary learning, which can be a significant barrier. Here we distinguish between *multidisciplinarity* (in which multiple disciplines provide separate viewpoints on a particular subject), *interdisciplinarity* (in which two or more disciplines are combined in an integrative way), and *transdisciplinarity* (in which the distinction between disciplines is transcended to create a new way of thinking) (Leavy, 2011). Since the field of transdisciplinary education is relatively new, concepts, methodologies, and assessment methods are still being developed and are likely to be profoundly different from traditional education.

2.3 *Onto-Epistemological Barriers*

Many scholars of transformative education have pointed out the necessity of changing entire frameworks and paradigms in order to work toward sustainable human–natural systems (Boström et al., 2018; Lotz-Sisitka et al., 2015; Macintyre et al., 2018; Odell et al., 2020; Sterling, 2011). We cannot expect conceptualizations and “solutions” arising from the same paradigm that gave rise to the climate crisis to meet the challenge. Further, a paradigm (in its broadest sense of a world view or framework with which we as cultures construct our reality) contains axioms, assumptions, and defaults that are usually invisible, and therefore unquestioned. Modern industrial cultures, for example, tend to default to short-term, linear, reductionist thinking. This “paradigm blindness” is a potentially serious barrier to conceptualizing the complex, nonlinear, spatially and temporally entangled problem of climate change and its disproportionate impacts on marginalized others. Thus, overcoming paradigm blindness is a necessary step toward imagining and considering alternatives to our current destructive path.

2.4 *Psychosocial Barriers*

While directly experiencing climate impacts such as extreme weather is likely to be detrimental to mental health, learning about climate change can also be psychologically challenging. In this author’s experience, students report such reactions as anger, depression, frustration, anxiety, and paralyzing despair when they learn about the climate crisis. These are difficult emotions to process, and teachers are not generally trained to handle them, especially in the sciences. Psychological challenges arise also from learning about alternative

epistemologies – we are, after all, entrenched in our own frameworks, and there may be resistance to reorienting ourselves to accept a different construction of reality. Additionally, in individualistic cultures such as those in the West (and increasingly elsewhere), students default to looking at the climate crisis as individuals, which can be overwhelming. These psychological barriers stand in the way of serious student engagement with the climate crisis, especially on a collective basis.

2.5 *Faculty Training and Institutional Barriers*

The lack of teacher support and training is a significant barrier to effective climate education. Additionally, structural barriers – such as the separateness of disciplines in a school or college setting, leading to the standardization and cementing of disciplinary boundaries, the lack of support for interdisciplinary and transdisciplinary teaching and learning communities, and ultimately, the “corporatization” of education to serve only the function of providing a workforce rather than also producing democratically engaged citizens – all make it difficult for radical alternatives to emerge and persist.

There are, broadly speaking, two models of climate change education that might serve as alternatives to the current unsatisfactory state of affairs. One is to find ways to teach climate within a discipline, starting from the disciplinary perspective, but going beyond it to transdisciplinarity: holistically connecting with other disciplines and the world at large. An expansion of model is a “teach across the curriculum” approach, in which students encounter climate change in multiple ways from multiple disciplinary perspectives, with the opportunity to meaningfully integrate these learnings across disciplines. The second, more radical, approach is to transform the entire education system – to take down the walls, so to speak, and foreground the dire complex of issues that confront us today: social inequality, climate change, biodiversity loss, and the entrenchment of systems of power.

This chapter describes pedagogical experiments within the first model that are informed by some of the radical aspirations of the second.

3 What Is an Effective Pedagogy of Climate Change?

I propose that an effective pedagogy of climate change:

- equips the student with a fundamental understanding of the basic science, impacts, and evidence of climate change, including its complex, nonlinear nature, and the future projections based on various scenarios: *the scientific-technological dimension*;

- enables the student to understand societal and ethical implications of climate change (climate justice), including intersections with economic, cultural, sociological, and non-anthropocentric perspectives; to understand how climate change is related to other major social-ecological problems and to critically examine proposed climate solutions from a climate justice perspective: *the transdisciplinary justice dimension*;
- enables the student to see the climate crisis as a symptom of a social-scientific framework or paradigm, and therefore to understand and articulate the need for new social-scientific frameworks in order to usefully engage with the crisis: *the epistemological dimension*;
- enables students to process difficult emotions related to the climate crisis and inspires them to play an active role in both mitigation (prevention of further climate change) and adaptation (dealing with aspects of climate change already under way): *the psychosocial-action dimension*.

4 Classroom Culture and Transformational Learning

Scientists who study climate have reported feelings of despair and anguish (Duggan, 2014). It is not surprising, therefore, that students in my class also report a range of negative emotions, from anger and frustration to denial and paralyzing despair, as we get deeper into our study of climate change. Unexamined, such reactions may hinder learning and pose a significant barrier to meaningful climate action. Climate scientist Steve Running has suggested that learning about climate change is equivalent to an emotional trauma, marked by emotional stages rather like the Kübler-Ross scale for grief and loss (Running, 2007; Wysham, 2012). The most important step toward overcoming the psychosocial barrier is to create a psychologically safe space in the classroom in which all students feel a sense of belonging, and to give students frequent opportunities to share their emotional responses to what they are learning. I make explicit the fact that learning about climate change is difficult, even (or especially) for climate scientists, and we discuss, critique, and use the adapted Kübler-Ross scale to acknowledge where we are emotionally at regular intervals during the semester. Poetry workshops led by an environmental poet, in which students get to express and share their fears, grief, anger, and despair, have been especially helpful in this regard.

To create a classroom culture centered on the nurturing, intellectual and emotional, of every student in the classroom, as well as on the building of a sense of community, is thus crucial. Transformative education calls on us to integrate the affective and cognitive aspects of learning. High academic

standards and the means for every student to achieve them are also crucial ingredients. My work is inspired by the work of Carol Dweck on mindsets (Dweck, 2006), Ken Bain on the “natural critical learning environment” (Bain, 2004), and a number of scholars in the area of transformational learning (Boström et al., 2018; Hoggan, 2018; Lotz-Sisitka et al., 2015; Macintyre et al., 2018; Odell et al., 2020; Sterling, 2011). For more details on building an alternative classroom culture, see Singh (2020).

5 Toward an Inter-to-Transdisciplinary Pedagogy of Climate Change

The framework I describe below is designed to address the five major barriers noted above, while attempting to realize the four dimensions of an effective pedagogy of climate change. It is to be noted that this is a work in progress, always informed and enriched by experiences with students in successive classes.

5.1 *Preparing the Ground*

At the planning stage, I lay out the class schedule and consider where course topics naturally align with climate science essentials. Defining climate science essentials is not a trivial task; for details, see Singh (2020). Meaningless piecemeal learning, a real danger when climate essentials are scattered through the semester, is avoided in part through the repeated use of a unifying visual tool (Figure 9.1).

On the first day of class, I survey the students on their current knowledge and feelings about climate change. This survey provides a baseline for student knowledge and beliefs. Within the first week, students are introduced in our planetarium to three satellite images of Earth seen from space: the dayside view, the nighttime view, and the nighttime image overlaid with population data.¹ Through guided inquiry and hypothesis-building, students “discover” the five Earth subsystem classifications used by scientists (Figure 9.1), the “human” impact on the biosphere, and the fact that not all humans are equally responsible, which enables them to co-construct Figure 9.1. This experience allows us to interrogate the term “Anthroposphere”, which implies that an undifferentiated “humanity” is equally responsible for, and equally impacted by, climate change. A discussion of possible alternatives leads us to the term “modern industrial civilization” as a more accurate substitute.

After this introductory experience, we study climate science wherever it aligns with physics topics during the course of the semester, with a Climate Week set aside near the end of term to weave all the threads together. At

FIGURE 9.1 The earth's subsystems and the three meta-concepts

semester's end, students complete a climate-related project. In all of these experiences, transdisciplinarity and justice issues are interwoven with the scientific. In every class in which we study climate change, we revisit Figure 9.1

and build in more layers of understanding, as contained in three overarching, transdisciplinary meta-concepts, which I developed in response to essential questions as well as to common misconceptions that emerged in my classroom and in the literature. Together with Figure 9.1, these meta-concepts provide a conceptual scaffolding that seeks to prevent piecemeal learning and takes students toward a more holistic understanding of the climate crisis and its impacts. As indicated by Figure 9.2 and elaborated below, the meta-concepts, once embedded in a transformative classroom culture, help realize all four dimensions of an effective pedagogy of climate change. Further, although my context is a single course rather than a more extensive or more formal program of study, this approach works toward students' achieving four of the five competencies identified as essential to any successful sustainability program: systems, normative, anticipatory, and interpersonal (Wiek et al., 2011).

Note that in the discussion of the three meta-concepts below, considerations of justice allow for transdisciplinary exploration.

FIGURE 9.2 The meta-conceptual framework foregrounding justice, embedded within an inclusive classroom culture inspired by transformational learning

5.2 *Meta-Concept: Balance-Imbalance*

We have an intuitive sense of what is meant by “balance” and “imbalance”, something we can readily demonstrate with our bodies. However, the concept

of dynamic balance (or “steady state”) is a little more subtle. In the climate context, its relevance can be seen both in terms of Earth’s energy balance (the greenhouse effect), and the accumulation of carbon dioxide in Earth’s atmosphere from prehistory to the present. If we consider the atmosphere to be like a giant bathtub (EPA, 2014), with water standing in for carbon dioxide, then all processes that contribute carbon dioxide to the atmosphere are *carbon sources*, analogous to the faucet. All processes that take out carbon dioxide from the atmosphere are *carbon sinks*, analogous to the drain. When water gushes out of the faucet at the same rate as it is removed by the drain, the water level in the bathtub remains constant. This is a steady state, or dynamic balance.

What happens when carbon sources act faster than carbon sinks? In the bathtub model, if we turn up the faucet and partially block the drain with a bit of soap, the water level will rise. This is precisely what happens to carbon dioxide in the atmosphere. Rates of change are notoriously difficult to teach in a classroom in which the mathematical level is limited to basic algebra, but an activity that involves the entire class helps to make these ideas “bodily” apparent (Singh, 2020).

This experience is introduced when the class has already discussed the relevant physics concepts. The “natural carbon cycle” and its disruption by the activities of “modern industrial civilization” are introduced via resources easily available on the internet (Donev et al., 2020; NOAA, 2019). We revisit Figure 9.1 to explore which Earth systems are involved in these processes. A graph of Earth’s atmospheric carbon dioxide concentration from 800,000 years ago (UNEP/GRID, 2019) provides a temporal context by dramatically illustrating the effect of modern industrial civilization on Earth’s systems, and makes clear that a little carbon dioxide goes a long way.

We discuss the evidence that current climate change is human caused, which presents an opportunity to interrogate, once again, the term Anthroposphere from a justice perspective. Are all humans equally responsible for the burning of fossil fuels and land use changes that result in rising carbon dioxide emissions? If not, who is responsible? These questions lead to comparisons by country (total and per capita) and examination of Gross Domestic Product and income levels as correlated to emissions (Ritchie & Roser, 2017). I also emphasize, throughout the course, our need to understand systems and structures – whether they are conceptual structures in physics or structures of power in society.

5.3 *Meta-Concept: Planetary Boundaries and Limits*

A system that is in dynamic balance can go into a state of imbalance when (in the example of the carbon cycle above) the carbon sources act faster than

the carbon sinks. Similarly, the energy balance of Earth's surface can be disturbed if greenhouse gas concentrations rise in the atmosphere, slowing the exit of infrared rays from Earth to space and raising the average global surface temperature. In Earth's 4.5-billion-year history, it has been in states of balance and imbalance on various timescales, due to multiple natural causes. Earth's departure from a balanced condition may be abrupt or it may be gradual, and a new steady state of balance may occur after a time. Not all balanced conditions in the past or future Earth are necessarily amenable to the existence of human civilization as we know it, or even to human survival as a species. However, the very existence of these two states, *balance* and *imbalance*, implies the existence of a transitional region, which may be narrow or broad, marking the pathways through which a system can go from balance to imbalance to a new and different balance.

The discussion of balance and imbalance thus leads naturally to the idea of “planetary boundaries” (Rockström et al., 2009). Nine proposed *planetary boundaries* (including climate change, biosphere integrity, ocean acidification, biogeochemical cycles, and land-use changes) make clear the indebtedness of human beings to multiple natural cycles, of which the carbon cycle is only one. While some class discussion time should be spent on a critique of this framework (Pickering & Persson, 2020), its value is twofold. One, it places the climate crisis into the larger context of socio-environmental crises, including the very serious one of biodiversity loss (Ceballos et al., 2015). Using this broader framework addresses the issue of the mainstream climate discourse's near-exclusive focus on climate change, without regard to its relationship with other socio-ecological problems. Treating climate change in isolation can encourage a “technofix” mentality, which might mitigate some aspects of the climate problem but could worsen or fail to address other factors that also substantially threaten the biosphere.

The second reason that the planetary boundaries framework is pedagogically useful is that in the climate context it allows for a discussion of “safe” thresholds of carbon dioxide derived from notions of “safe limits” to global temperature rise. We consider the Copenhagen limit of 2°C, and the aspirational Paris limit of 1.5°C (Espinosa, 2018). A temperature limit implies a limit to how much carbon dioxide can continue to be emitted (Meinshausen et al., 2009), and modern industrial civilization already has enough fossil fuels in reserve to violate the CO₂ “safe” limit (for 2°C) five times over (Leaton, 2011). This inquiry naturally leads to a discussion of who is responsible and who bears the consequences. Briefly, we examine the illogic of an economic system fueled by endless growth (see the chapter by Dhara and Singh in this volume). Students view a TED talk by Kate Raworth (Raworth, 2018) as an imagination-expanding

exercise indicating that scholars are thinking of alternatives to mainstream economics and projecting future emissions based on socioeconomic pathways (Tollefson, 2020).

Now the large circle in Figure 9.1 is seen to symbolize not only Earth, but also planetary boundaries and limits beyond which Earth's subsystems can go from balance to imbalance.

5.4 *Meta-Concept: Complexity*

What is the *nature* of the interactions between the subsystems displayed in Figure 9.1? How might these interactions lead the Earth system as a whole from balance to imbalance? Is it possible to turn the system back from crossing a planetary boundary? Can we predict the point at which climate change becomes catastrophic and uncontrollable?

These questions all point toward a key feature of the climate system: *complexity*. Complex systems science is relatively new; such basics as definitions and measures of complexity are still being elucidated (Bar-Yam, 2002; Fieguth, 2017). For this and other reasons, complexity is a significant onto-epistemological barrier to understanding climate change. Nevertheless, as scholars have pointed out (Roychoudhury et al., 2017), considering the implications of climate as a complex system is crucial to understanding – and teaching – some of its most important and surprising features.

I introduce a complex system as one which, like a simple system, may be considered as composed of parts. The analog clock serves as a powerful metaphor for a simple system: if we take it apart and understand what each part is and what it does, we have understood the clock. It may be complicated, but it is not complex. By contrast, a complex system is one in which the interactions are as important as the parts; indeed, the interactions may change the nature and behavior of the parts. I invoke the Aristotelian dictum “The whole is greater than the sum of its parts” as a description of a complex system. All this sounds rather abstract, but when I provide some examples of complex systems and invite the students to add their own examples, everyday manifestations of complexity become suddenly apparent. We discuss the human endocrine system, the nervous system, ecosystems, and the climate. From these we note certain broad features of complex systems: the presence of multiple interacting feedback loops, stabilizing and destabilizing; the nonlinearity of interactions; and the possibility of tipping points, which, if crossed, can cause large scale systemic changes that in the case of climate are typically irreversible on human timescales. Initially, small, local effects might propagate and proliferate through the system very quickly, in ways that may not be obvious, via complex causal connections (Grotzer, 2012) – resulting in sudden shifts, “surprises”,

for which the predictive power of Newtonian physics (studied thus far) is inadequate.

The Arctic provides some of the most pedagogically useful examples of potentially destabilizing feedback loops, such as the well-known ice albedo feedback (Stuecker et al., 2018). Although their climatic impact is still being quantified, it is useful for students to “discover” how some of these feedback loops can interact, illustrating how the climate problem could get critical very fast. The idea of tipping points (Lenton et al., 2019) then acquires plausibility. Our discussion of complexity thus effectively does away with any misconception that we can wait to address climate change, or that it would be a simple matter to fix it. Visual tools, classroom discussions, and laboratory exercises reinforce the importance of complex systems.

5.5 *Putting It All Together*

When we study complex systems, students often ask how it is that they have never come across these concepts before. This lack is a symptom of the utter inadequacy of a reductionist, siloed education system that ignores complexity in a world in which most systems, social and natural, are complex. The faults of the education system – reductionism, mechanism, atomism, and its hierarchical nature – are also features of the dominant social-economic paradigm that has led to the complex of crises that confront us today. Interestingly, the origins of this paradigm can be traced in part to the history of classical physics and the development of what is known as the Newtonian Paradigm or the Mechanistic Paradigm. We study its characteristics (reductionism, atomism, determinism, and predictability) and its wider social-historical implications (Hobson, 2009; Shapin, 2018), including how it manifests in our education system, in our social arrangements, and in our economics, described in more detail elsewhere (Singh, 2020). Our study of alternative ways of being, comparing Indigenous knowledge systems with the Newtonian Paradigm (Kawagley & Barnhardt, 2005) offers the chance for a disorienting dilemma (Mezirow & Taylor, 2009) in which the inadequacy of our current paradigms becomes apparent (Bain, 2004), and justice issues can be revisited.

Our exploration of the three meta-concepts is already interdisciplinary; however, setting aside time to explicitly study the transdisciplinary dimension allows us to bring different threads together more explicitly, emphasizing that climate change exists at the intersection of multiple disciplines, and allowing for a deeper elaboration of climate justice. During Climate Week, when significant class time and one laboratory are focused on this inquiry, the exploration unfolds in three ways:

- Through the use of topical news reports on environmental and climatic impacts that transcend disciplines.²
- Through the exploration of climate movements and Indigenous movements, and Indigenous peoples' agency and role in climate mitigation.³
- Through an interdisciplinary project with a service component. Inspired by project-based learning and transformational learning, short-term projects give students an experiential sense of the transdisciplinary nature of the climate crisis.⁴

All three meta-concepts – balance-imbalance, planetary limits, and complexity – address the barrier that we call “knowledge pollution and ignorance” by presenting the essentials of climate science in a coherent framework. A discussion of justice within each allows us to explore beyond the sciences, thus overcoming the barrier presented by transdisciplinarity. Our study of complex systems in particular addresses the epistemological challenge. The classroom culture, informed by transformational learning, and our explicit discussion of the affective impact of learning about climate change, allows us to engage with the psychosocial barrier, and the class project helps students realize their own agency. The use of Figure 9.1 as a unifying visual tool, along with activities during Climate Week and the class project allow us to avoid piecemeal learning, which is a consequence of the fifth barrier, namely, lack of teacher training and structural and logistical issues. This last is a serious one, as I discuss later.

I will not elaborate here on how this framework helps us build a justice-based set of criteria for evaluating climate solutions; details can be found elsewhere (Singh, 2020).

6 Conclusion

The approach described in this chapter has been developed in different stages over nearly a decade, primarily in a course for non-science majors called Physics, Nature, and Society. Unlike a single intervention that can be tested via before-and-after surveys or control groups, this approach is a comprehensive framework or philosophy, always subject to improvement, with multiple interdependent elements; moreover, it is inter-to-transdisciplinary in ethos and practice. Transdisciplinary methodologies and those of transformational learning are not reductive or piecemeal, and therefore not amenable to conventional tests and measures of efficacy. The student-teacher community in the classroom is itself a complex system; there is recent work on applying

complex systems science to education (for example, Forsman et al., 2014), but the field is still being developed. For all these reasons I do not aggregate the classroom size (from nine to 15 students, typically) over eight years of teaching for statistical analysis; nor do I divide the class into test subjects and controls. Instead, as a member of the classroom community rather than a remote experimenter, I adopt a participant-observer approach, consistent with the philosophy of an inclusive, welcoming, intellectually challenging community in which everyone is valued, and mutually-agreed-upon standards are high. Because my pedagogy is transparent, every two weeks students provide anonymous feedback on their learning experience. Based on these, along with classroom discussions, written reflections, start-of-semester and end-of-semester surveys, multiple one-on-one conversations, homework, and test and exam questions, I can make the following statements:

- An overwhelming majority of students, typically 80 to 90% report a new or renewed interest in physics, climate change, and climate science.
- A similar majority of students self-report greater understanding of the scientific and sociological aspects of climate change; this increase in understanding is borne out by homework submissions, tests, and exams.
- By the end of the semester, most students demonstrate an increased fluency with transdisciplinarity and a systems approach, as indicated by their comfort using Figure 9.1 for oral explanations and presentations in class.
- Student presentations, as well as short-essay questions on exams, demonstrate a generally adequate understanding of such ideas as paradigms, paradigm shifts, and alternative epistemologies.
- Students appreciate the open, community-oriented, collaborative atmosphere in the classroom, and some have explicitly mentioned that this is one class in which they feel that their ideas matter.
- Students appreciate the transdisciplinary approach, including opportunities for discussion, embodied learning, working in groups, and working on projects that make a difference. They come to see science as relevant to wider concerns in the world.
- Students welcome the chance to talk about how they *feel* about climate change.

This approach in its current form has at least two interrelated shortcomings. One, I can make no claim that this course by itself transforms students. Transformational learning emphasizes both cognitive and emotional shifts in perspective (Hoggan, 2018), and while I have preliminary evidence of such shifts in the classroom, one semester is insufficient to judge whether transformational change – which implies that one can never go back to thinking in the

old way after the epistemic shift – has actually taken place. Since such a shift need not result from a single experience and may arise because of a person having crossed a number of thresholds, over a long period, I can only make this tentative claim: that the framework as described and implemented seems to help the majority of students cross at least a few of the thresholds leading toward transformational learning.

This shortcoming is related to the second drawback: that the benefits of this approach are probably lost or eroded over time, since it is unlikely to be reinforced in other, more conventional-style classes. My experiences with organizing three interdisciplinary climate teach-ins at my institution and co-leading an interdisciplinary workshop for Massachusetts high school science teachers in 2017, indicate that there is great interest, enthusiasm, and indeed, hunger among educators to engage with the climate crisis in new ways. A groundswell at the grassroots is likely to be the best option for lasting and meaningful change in the education sector; however, structural and institutional barriers make it extremely difficult to realize such a change. Thus, we have the phenomenon of dedicated educators with radical visions working in isolation, limiting their impact in space and time. This state of affairs points to the urgent need for education administrators as well as faculty to undergo their own epistemic shifts. As a first step toward the complete transformation of the education system, it is highly recommended that educators experiment with climate and environmental education *across the curriculum*, but in a way that results in transformational learning for the educators themselves. This step will require institutional support for faculty (and administrator) training in transformational learning and transdisciplinary pedagogy, which will challenge many strongly held preferences for conventional teaching. It will mean creating opportunities for faculty collaboration and peer learning across disciplines and encouraging “transgressive” (that is, unorthodox and norm-disrupting) pedagogical experimentation so as to enable the continued development, articulation, and adaptation of a variety of context-specific approaches by different educator-student communities across the planet.

Notes

- 1 In the absence of a planetarium, images may be used, for example: <https://www.nasa.gov/topics/earth/images/index.html>, <https://earthobservatory.nasa.gov/images/79793/city-lights-of-africa-europe-and-the-middle-east>, https://neo.sci.gsfc.nasa.gov/view.php?datasetId=SEDAC_POP
- 2 For example, the excellent article by CNN reporter John D. Sutter: *What Killed Stacy Ruffin?* (Sutter, 2017).

- 3 For example Inupiaq culture in Northern Alaska (Singh, 2015), the Dongria Kondh of Odisha, India (Tatpati et al., 2016); Also, Reyta & Veit (2016) and Scheidel et al. (2020).
- 4 These projects range in scope and scale from modest (presenting the essentials of climate science to another classroom) to more ambitious (exploring the local climatic impact of heat waves on the elderly, and creating an impact awareness tool for the local town's health department).

References

- Bain, K. (2004). What makes great teachers great? *The Chronicle of Higher Education: The Chronicle Review*, 50(31), B7.
- Bar-Yam, Y. (2002). General features of complex systems. In Y. Bar-Yam (Ed.), *Knowledge management, organizational intelligence and learning, and complexity* (Vol. 1). EOLSS Publishers, UNESCO. <http://www.eolss.net/sample-chapters/c15/E1-29-01-00.pdf>
- Boström, M., Andersson, E., Berg, M., Gustafsson, K., Gustavsson, E., Hysing, E., Lidskog, R., ... Öhman, J. (2018). Conditions for transformative learning for sustainable development: A theoretical review and approach. *Sustainability*, 10, 4479.
- Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human-induced species losses: Entering the sixth mass extinction. *Science Advances*, 1(5), e1400253. <https://doi.org/10.1126/sciadv.1400253>
- Donev, J., Hanania, J., & Stenhouse, K. (2020). Energy education: Natural carbon cycle. In *Energy education encyclopedia*. University of Calgary. https://energyeducation.ca/encyclopedia/Natural_carbon_cycle
- Duggan, J. (Ed.). (2014, 2020). This is how scientists feel. In J. Duggan (Ed.), *Is this how you feel?* <https://www.isthishowyoufeel.com/this-is-how-scientists-feel.html>
- Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.
- EPA [Environmental Protection Agency]. (2014). *Causes of climate change* (Archived version, before revision by EPA). US Environmental Protection Agency. <https://archive.epa.gov/epa/climate-change-science/causes-climate-change.html>
- Espinosa, P. (2018, March 20). *The Paris agreement: A strategy for the longer term*. World Resources Institute. <https://www.wri.org/climate/expert-perspective/paris-agreement-strategy-longer-term>
- Fieguth, P. (2017). *An introduction to complex systems: Society, ecology and nonlinear dynamics*. Springer.
- Forsman, J., Moll, R., & Linder, C. (2014). Extending the theoretical framing for physics education research: An illustrative application of complexity science. *Physics Review Physical Education Research*, 10(2), 020122. <https://doi.org/10.1103/PhysRevSTPER.10.020122>

- Grotzer, T. (2012). *Teaching causality in a complex world*. R&L Education.
- Hobson, A. (2009). *Physics: Concepts and connections* (5th ed.). Pearson.
- Hoggan, C. D. (2018). The current state of transformative learning theory: A metatheory. *Phronesis*, 7(3), 18–25. <https://doi.org/10.7202/1054405ar>
- IPCC [Intergovernmental Panel on Climate Change]. (2018). *Global warming of 1.5°C*. <https://www.ipcc.ch/sr15/>
- Kwauk, C. (2020). *Roadmaps to quality education in a time of climate change*. Brookings. <https://www.brookings.edu/research/roadblocks-to-quality-education-in-a-time-of-climate-change/>
- Leaton, J. (2011). *Unburnable carbon: Are the world's financial markets carrying a carbon bubble?* Carbon Tracker Initiative.
- Leavy, P. (2011). *Essentials of transdisciplinary research* (1st ed.). Routledge.
- Lenton, T. M., Rockström, J., Gaffney, O., Rahmstorf, S., Richardson, K., Steffen, W., & Schellnhuber, H. J. (2019). Climate tipping points: Too risky to bet against. *Nature*, 575, 592–595. <https://doi.org/10.1038/d41586-019-03595-0>
- Levy, B. S., & Patz, J. A. (2015). Climate change, human rights, and social justice. *Annals of Global Health*, 81(3), 310–322. <https://doi.org/10.1016/j.aogh.2015.08.008>
- Lotz-Sisitka, H., Wals, A. E. J., Kronlid, D., & McGarry, D. (2015). Transformative, transgressive social learning: Rethinking higher education pedagogy in times of systemic global dysfunction. *Current Opinion in Environmental Sustainability*, 16. <http://www.openensemble.se/wp-content/uploads/2018/08/lotzswalskronlidmcgarytransgressivesociallearning.pdf>
- Macintyre, T., Lotz-Sisitka, H., Wals, A., Vogel, C., & Tassone, V. (2018). Towards transformative social learning on the path to 1.5 degrees. *Current Opinion in Environmental Sustainability*, 31, 80–87. <https://doi.org/10.1016/j.cosust.2017.12.003>
- Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., ... Allen, M. R. (2009). Greenhouse-gas emission targets for limiting global warming to 2 °C. *Nature*, 458(7242), 1158–1162. <https://doi.org/10.1038/nature08017>
- Mezirow, J., & Taylor, E. W. (Eds.). (2009). *Transformative learning in practice: Insights from community, workplace, and higher education*. Wiley.
- NOAA [National Oceanic and Atmospheric Administration]. (2019, February). *Carbon cycle*. <https://www.noaa.gov/education/resource-collections/climate/carbon-cycle>
- Odell, V., Molthan-Hill, P., Martin, S., & Sterling, S. (2020). Transformative education to address all sustainable development goals. In W. Leal Filho, A. M. Azul, L. Brandli, P. G. Özuyar, & T. Wall (Eds.), *Quality education: Encyclopedia of the UN sustainable development goals* (pp. 905–916). Springer. https://doi.org/10.1007/978-3-319-95870-5_106
- Pickering, J., & Persson, Å. (2020). Democratising planetary boundaries: Experts, social values and deliberative risk evaluation in Earth system governance. *Journal of*

- Environmental Policy & Planning*, 22(1), 59–71. <https://doi.org/10.1080/1523908X.2019.1661233>
- Raworth, K. (2018, April). A healthy economy should be designed to thrive, not grow. *TED* https://www.ted.com/talks/kate_raworth_a_healthy_economy_should_be_designed_to_thrive_not_grow?language=en
- Reytar, K., & Veit, P. (2016, November). *Indigenous people and local communities are the world's secret weapon in curbing climate change*. World Resources Institute. <https://www.wri.org/blog/2016/11/indigenous-peoples-and-local-communities-are-worlds-secret-weapon-curbing-climate-change>.)
- Ritchie, H., & Roser, M. (2017). CO₂ and greenhouse gas emissions. *Our world in data*. <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>
- Robinson, M. (2019). *Climate justice: Hope, resilience, and the fight for a sustainable future* (Reprint). Bloomsbury.
- Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S. I., Lambin, E., ... Foley, J. (2009). Planetary boundaries: Exploring the safe operating space for humanity. *Ecology and Society*, 14(2). <https://doi.org/10.5751/ES-03180-140232>
- Roychoudhury, A., Shepardson, D. P., & Hirsch, A. S. (2017). System thinking and teaching in the context of climate system and climate change. In *Teaching and learning about climate change: A framework for educators* (1st ed.). Routledge.
- Running, S. W. (2007). The 5 stages of climate grief. *Numerical Terradynamic Simulation Group Publications*, 173. https://scholarworks.umt.edu/ntsg_pubs/173
- Scheidel, A., Bene, D. D., Liu, J., Navas, G., Mingorría, S., Demaria, F., ... Martínez-Alier, J. (2020). Environmental conflicts and defenders: A global overview. *Global Environmental Change*, 63, 102104. <https://doi.org/10.1016/j.gloenvcha.2020.102104>
- Shapin, S. (2018). *The scientific revolution* (2nd ed.). University of Chicago Press.
- Singh, V. (2015, January 21). *To drill or not to drill? A dilemma in the context of climate change in the Arctic: STIRS student case study*. Association of American Colleges & Universities. <https://www.aacu.org/stirs/casestudies/singh>
- Singh, V. (2020). *Toward an effective pedagogy of climate change: Lessons from a physics classroom* (Preprint). <http://arxiv.org/abs/2008.00281>
- Sterling, S. (2011). Transformative learning and sustainability: Sketching the conceptual ground. *Learning and Teaching in Higher Education*, 5, 17–33.
- Stuecker, M. F., Bitz, C. M., Armour, K. C., Proistosescu, C., Kang, S. M., Xie, S.-P., ... Jin, F.-F. (2018). Polar amplification dominated by local forcing and feedbacks. *Nature Climate Change*, 8(12), 1076–1081. <https://doi.org/10.1038/s41558-018-0339-y>
- Sutter, J. D. (2017). What killed Stacy Ruffin? *CNN*. <https://www.cnn.com/2017/08/11/health/sutter-louisiana-flood-stacy-ruffin/index.html>
- Tatpati, M., Kothari, A., & Mishra, R. (2016). *The Niyamgiri story: Challenging the idea of growth without limits?* Kalpavriksh. <https://kalpavriksh.org/wp-content/uploads/2018/06/NiyamgircasestudyJuly2016.pdf>

Tollefson, J. (2020). How hot will earth get by 2100? *Nature*, 580, 443–445.

<https://doi.org/10.1038/d41586-020-01125-x>

UNEP-GRID [UN Environment Programme - Global Resource Information Database Geneva]. (2019). *Trends in atmospheric carbon dioxide concentration over 800,000 years*. https://graphs.unepgrid.ch/graph_global_co2_concentration_800000.php

Wysham, D. (2012, September). *The six stages of climate grief*. Otherwords.

https://otherwords.org/the_six_stages_of_climate_grief/