ONE HUNDRED YEARS:

A COLLECTIVE CASE STUDY OF CLIMATE CHANGE EDUCATION IN GEORGIA

by

LEONARD MARK BLOCH

(Under the Direction of David Freeman Jackson)

ABSTRACT

This collective case study examined how five K-12 science teachers taught about climate change during Fall 2013, and asked how the University of Georgia can support climate change education. The participants were all experienced teachers, and included: three high school teachers, a middle school teacher, and an elementary school teacher. 'Postcarbonism', an emerging theoretical framework, shaped the research and guided the analysis. The teachers varied in their teaching practices and in their conceptions of 'climate change', but they were united in: 1) their focus on mitigation over adaptation, and 2) presenting climate change as a remote problem with simple solutions. The teachers drew on varied resources, but in all cases, their most valuable resources were their own skills, knowledge and personality. The University of Georgia can support climate change education by developing locally relevant educational resources. Curriculum developers might consider building upon the work of outstanding teachers.

INDEX WORDS: Climate change, Science teachers, K-12 education, Experienced teachers, Educational resources, Case study research, Postcarbonism.

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DEDICATION

To a curly-haired girl, who I imagine has children of her own by now.

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I could not have written this dissertation without the support of many teachers. I offer my deepest gratitude to the five teachers who welcomed me into their classrooms, agreed to talk with me, reviewed drafts, and every day act on their deep commitment to helping their students learn.

Dr. David Jackson has been a touchstone, and he has always been kind. Even when the works I put before him were the coarsest alloys, he responded as though there were hints of gold within, and this gave me the confidence to face my glowering laptop. As my fingers tapped out these words, I imagined Drs. Kathleen deMarrais, Mark Farmer, Ajay Sharma, and J. Marshall Shepherd reading them. Dr. Mike U. Smith removed himself from the committee, but his service was invaluable.

My mother, Dr. Julia Rauch, my father, Dr. Peter Bloch, and my brother, Dr. Martin Bloch, have provided a lifetime's worth of love. For decades, I took pride in the fact that I was the only member of my immediate family who did not presume after the title of 'Dr.'. Now I must swallow that pride and try to live the rest of my life in humility.

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I acknowledge all of the teachers who guided me as a child. They taught me basic skills while inspiring my love of learning. I would like to single out Janet M. Goldstein, or Teacher Janet, as I called her. To be honest: I hated high school English; I wasn’t fond of her; and I doubt I was her favorite student. But by teaching me how sentences ‘should’ be written, she started a process that allows me to use colons, semicolons, and single quotation marks as toys for my amusement.

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If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years.

– *The Limits to Growth (1972)*

[…] pues estaba previsto que la ciudad de los espejos (o espejismos) sería arrasada por el viento y desterrada de la memoria de los hombres, en el instante en que Aureliano Babilonia acabara de decifrar los pergaminos, y que todo lo escrito en ellos era irrepetible desde siempre y para siempre, porque los estirpes condenados a cien años de soledad no tenían una segunda oportunidad sobre la tierra.

[…] it was foreseen that the city of mirrors (or mirages) would be wiped out by the wind and exiled from the memory of men at the precise moment when Aureliano Babilonia would finish deciphering the parchments, and that everything written on them was unrepeatable since time immemorial and forever more, because races condemned to one hundred years of solitude did not have a second opportunity on earth.

– Gabriel García Márquez

一年树谷
十年树木
百年树人

One year, raise grain.
Ten years, raise trees.
One hundred years, raise children.

– Attributed to Guanzi

CHAPTER 1

INTRODUCTION

Two years later, as I faced the committee, I would remember the afternoon of June 24, 2012, when I bought my first air conditioner. At the time, much of the country was blanketed in heat. By June 29, the temperature in Athens, GA would hit 109°F. In September, the extent and volume of Arctic sea ice would hit historic lows, and in October, Superstorm Sandy would hit New Jersey. I have spent much of the last two years trying to figure out how to answer if a child asks me whether 2012's weird weather was caused by climate change.

I still do not know.

Climate change is gaining attention within science education. The terms 'global warming', 'greenhouse effect', and 'climate change' appeared nowhere in the 1993 *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) or the 1996 *National Science Education Standards* (National Research Council, 1996).[1] The 2009 update of the *Benchmarks* (American Association for the Advancement of Science, 2009) and the 2012 *Framework for K-12 Science Education* (National Research Council, 2012), gave much greater attention to climate change. The *Framework* emphasized 'global climate change' as a disciplinary core idea in earth and space science, and mentioned it repeatedly when discussing life science. Under the *Next Generation Science Standards* (NGSS) (Achieve Inc., 2013): 1) Kindergarteners will

[1] The *Standards* mentioned 'greenhouse gases' in a footnote (p. 179).

investigate how humans alter our environment and discuss ways we can reduce our environmental impact; 2) Middle school students will engage with the evidence for climate change; and 3) High school students will address climate science in multiple subjects. Future science teachers, including elementary and middle school teachers, will devote much more time to climate change than they have in the past.

Teaching climate science presents teachers with many challenges. Climate change has become a divisive social and political issue (Hoffman, 2012; Hulme, 2009), and Pascopella (2012) called it the "new evolution debate". Climate change can stir negative emotions in both students and teachers (Lombardi & Sinatra, 2012). Many science teachers are not well versed in climate science (Wise, 2010), and many textbooks do not cover it. Important aspects of climate change science are highly uncertain, and even teachers who are up-to-date with the science would struggle to answer simple questions that students might ask.

The NGSS may shift teaching practices around climate change and documenting current practice may aid future researchers. More importantly, teachers who lack experience teaching about climate change may benefit from reflecting on the practice of experienced teachers. This dissertation seeks to understand K-12 classroom science teacher[2] practices, the challenges teachers face, and how the University of Georgia might support teachers in educating children about climate change. In particular, I seek to answer five research questions.

RQ1: What do teachers teach about climate change?

RQ2: How do teachers teach about climate change?

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[2] Hereafter I will refer to 'K-12 classroom science teachers' as 'teachers'.

RQ3: What resources do teachers use in teaching and learning about climate change?

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

Justification

Justifying an action involves stating the reasons for the action; this can initiate an endless cycle if the stated reasons in turn need to be justified. I have hinted that the importance of climate change within the NGSS justifies my research. But this begs the question of why we should attend to the NGSS. An appeal to authority is ample justification in some situations. But it is a shallow justification for a dissertation. In fact, my reasons for undertaking this dissertation have little to do with the NGSS.

The Western tradition of moral philosophy has looked into the foundations of ethical action, and has proposed two broad categories of justification that might serve as moral axioms. I will call these the 'utilitarian' and 'principled' justifications for action. In this section, I will look at each of these, before turning to a variation on the utilitarian justification that Mohandas Gandhi proposed towards the end of his life. I will attempt to show that my efforts in writing this dissertation are well justified within each of these traditions.

Utilitarianism

The utilitarian tradition demands that ethical actors think through the likely consequences of their actions. Jeremy Bentham (1748/1988) proposed that actions should be judged based on whether they are likely to promote human happiness, which in turn depends on balancing human pleasure and pain.

> Nature has placed mankind under the governance of two sovereign masters, pain and pleasure. It is for them alone to point out what we ought to do, as well as to determine what we shall do. On the one hand the standard of right and wrong, on the other the chain of causes and effects, are fastened to the throne. They govern us in all we do, in all we say, in all we think: every effort we can make to throw off your subjection, will serve but to demonstrate and confirm it. In words a man may pretend to abjure their empire: but in reality he will remain subject to it all the while. The principle of utility recognizes this subjection, and assumes it for the foundation of that system, the object of which is to rear the fabric of felicity by the hands of reason and of law. (pp. 1-2)

As I will discuss in the next chapter, climate change seems poised to cause much suffering. To the degree that climate change causes death, it diminishes the opportunity for human happiness. Moreover, actions taken–or not taken–towards mitigating climate change in the coming decades, will likely impact future generations for as long as humans walk the Earth. Given the long-term potential of the human species, climate change might diminish the pleasure and increase the pain of hundreds of billions of human beings.

This dissertation focuses on K-12 climate change education in the hope that educational efforts directed at children may spark lifelong learning about climate change. Hopefully, these lifelong learners: 1) will be able to adapt to life on a changing planet, 2) will take action to mitigate the suffering caused by future climate change, and 3) will educate the next generation. The dissertation focuses on teachers, because individual teachers impact large numbers of children. Efforts to support teachers could impact very large numbers of children and uncountable numbers of unborn people.

Bentham's utilitarianism provides ample justification for working to support teachers in their efforts to teach about climate change. I agree with Utilitarians that justifying any action involves considering the likely results of the action. But if pain and pleasure reign over humanity, they are petty despots, and we should not willingly bow before them. In the next section, I will propose that ethical actors may serve two different masters. My eloquence will pale before Bentham's, but I hope that upon reading the sovereigns' names the reader will acknowledge my subservience, and will thereby understand my reasons for doing this work.

Principled Action

Humans have limited ability to predict the outcomes of our actions, and this fact undermines the foundations of utilitarianism. Another tradition within Western moral philosophy says that human beings should act in accordance with moral principles. Kant (1785/1998) proposed a reasoned foundation for principled action, in the form of a categorical imperative, "*I ought never to act except in such a way that I could also will that my maxim should become a universal law*" (p. 15).

In considering this imperative, and my personal conviction that pleasure and pain do not provide a sound foundation for moral action, I propose the following maxim:

> *Individuals should act in a manner that they believe will imbue their lives with a sense of meaning and purpose.*

Throughout history people have been willing to foreswear great pleasure and undergo extreme pain–and even death–because they were pursuing a sense of meaning and purpose. The examples are myriad: Millions of people have given up the pleasures of civilian life and risked pain and death in military service, and almost every woman who has willingly suffered the pains of childbirth has done so, at least in part, because she found meaning and purpose in bringing forth new life.

The proposed maxim meets the demands of Kant's categorical imperative. Individuals who pursue meaning and purpose are more likely to live lives of meaning and purpose than those who disregard the maxim. Moreover, they may act as models for others, who may be inspired to pursue meaning and purpose in their own lives. Finally, many individuals find meaning and purpose in service to their community and in acts of individual, familial, and universal love, so in pursuing meaning and purpose, they pursue other goods as well.

I find meaning and purpose in working with children, in supporting teachers, and in concerning myself with the needs of the larger human community. I undertook this study in the belief that it would imbue my life with meaning and purpose. I have not been disappointed.

Gandhian Utilitarianism

So far, I have discussed two strands within Western moral philosophy. Gandhi was little schooled in Western philosophy but deeply engaged in the world. Towards the end of his life, he wrote to a friend offering a "talisman" to guide human action:

> Whenever you are in doubt, or when the self becomes too much with you, apply the following test. Recall the face of the poorest and the weakest

> man whom you may have seen, and ask yourself, if the step you contemplate is going to be of any use to *him*. Will he gain anything by it? Will it restore him … control over his own life and destiny? In other words, will it lead to Swaraj [Self-rule] for the hungry and spiritually starving millions? Then you will find your doubts and … self melt away. (Pyarelal, 1958, p. 65)

Humans are naturally inclined to feel compassion for other people. By focusing on one person, we may make better judgments than we would if we focus on abstractions, like 'the greatest happiness for the greatest number', or 'meaning and purpose'.

Gandhi spent far more of his life living among the poor and weak than I have. In fact, I have never set foot inside one of the urban third world slums that house many of the poorest human beings on Earth. But twice in my life, I spent brief periods among the rural poor of the third world. Both communities were housed in tin-roofed shacks; neither emitted significant amounts of greenhouse gases. I spent some time among the Hill People in Thailand, but I will discuss a second community.

In 1989, I spent two weeks on a remote island in Fiji. The islanders seemed happy to live by the beach as the trade winds blew away the summer heat. One man told me that life was not always so pleasant. During the rainy season when hurricanes were more common, they would leave their beachside dwellings and seek refuge in the mountains. Every family seemed to have a garden, and they ate a lot of fish. The income from western tourists allowed them to purchase rice and diesel for a generator that was housed under a large thatched roof mounted on stilts. At night, people would enjoy each other's company and listen to music under the only electric lights on the island. I was so enchanted by the community, that I briefly considered the offer to move there and teach in their school. I remember some of the children's faces, and using Gandhi's talisman, I will recall the face of one curly-haired girl, who I imagine has children of her own by now. She was around eight years old, clothed in an old T-shirt and shorts, and seemed somewhat frightened by the young white man who gazed at her.

It might seem that this girl gains nothing from my work with teachers in Georgia. But if she is now a mother, and if she loves her children, and if she hopes that they will continue to enjoy life on their idyllic island home far from Asia's slums, then she may have much to gain. If she still lives on that small island, or if she has moved to a nearby island to live with her husband's family–even if she lives in an urban slum–then she and her family have done almost nothing to contribute to climate change. But as I will discuss in the next chapter, residents of small islands are especially vulnerable to climate change. If my work helps teachers to inspire children to take measures to mitigate climate change, then it may be of great use to this woman and her children.

One might ask whether I might better serve her by researching climate change education on remote islands in Fiji. Three considerations advise against it. First, I am familiar with educational practice in America, and my skills might be better used in America. Second, this is a student project, and I can do better work by maintaining close contact with my advisor and others in my support system. Third, I am doing this dissertation under the auspices of the University of Georgia, and that creates an obligation that I also serve Georgia's residents. I will return to the question of climate change education in small island states in the concluding chapter of this dissertation.

Definitions of Terms

The public often conflates ‘climate change’, ‘global warming’, ‘the greenhouse effect’, and ‘global environmental change’, but I will differentiate them. Three other scientific terms may not be familiar to some readers, so I will define them too.

Climate: A statistical description (including measures of mean and variability) of atmospheric conditions (including temperature, precipitation, and wind speed) at the surface of the Earth. Classically meteorologists analyze statistics measured over periods of 30 years or more when discussing climate. Because of my interest in climate change, I may refer to shorter time spans.

Climate Change: In general, I will follow the Intergovernmental Panel on Climate Change (IPCC) (2014a).

> […] a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings […]. (p. 3)

This differs from the definition found in the United Nations Framework Convention on Climate Change (UNFCCC) (1992).

> […] a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. (Article One)

The definitions differ in two important points. First, the IPCC definition recognizes that climate change can be natural or anthropogenic, while the UNFCCC definition only addresses anthropogenic climate change. Unless otherwise indicated, in discussing climate change since 1880, I mean to emphasize 'anthropogenic climate change' and when discussing climate change before 1880, I mean to emphasize 'natural climate change'. When a clear distinction is needed, I will specify "natural climate change" or "anthropogenic climate change". Second, the UNFCCC focuses on changes resulting from alterations to the global atmosphere, but the IPCC definition doesn't limit itself. By including local and regional climate change, as well as changes resulting from alterations in land use, within the compass of 'climate change', I will be impelled to make several assertions and recommendations that would not be called for under the UNFCCC definition of 'climate change'.

Climate sensitivity: The change in global mean surface temperature at equilibrium caused by a doubling of the atmospheric CO_2 concentration from pre-industrial levels. The IPCC (2013c, p. 16) estimated climate sensitivity at between 1.5°C and 4.5°C.[3]

Global Environmental Change: Changes in the atmosphere, biosphere, cryosphere, hydrosphere, and/or lithosphere. Global climate change cannot be understood in isolation from other aspects of global environmental change. In particular, changes in ice cover, ocean temperature, and ocean pH are so intimately linked with climate change that I consider them aspects of climate change.

[3] Kummer and Dessler (2014) argued that the lower part of this estimate is unlikely and the climate sensitivity might be much higher than the IPCC estimate. The structure of their argument suggests that it might make more sense to measure sensitivity in $°C/(W/m^2)$ instead of $°C/(2 \times [CO_2])$. Evaluating sensitivity for forcings other than CO_2 allows a more nuanced discussion. At present few teachers discuss sensitivity or forcings, but well-educated laypeople would be familiar with both terms. Science teachers may not want to blindly adopt the IPCC definition.

Global Warming: An increase in average global surface temperature over an extended period, typically decades or longer.

Greenhouse Effect: In general I will follow IPCC (2012).

> Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. (p. 560)

Since 1750, humans have emitted over 600 gigatons of greenhouse gases into the atmosphere (Allen, 2009), causing a radiative forcing. Many people refer to this forcing as "the greenhouse effect". I will refer to it as "the enhanced greenhouse effect".

Radiative forcing: The change in energy flux caused by a driver (such as CO_2 or black soot) calculated at the tropopause. Total anthropogenic radiative forcing since 1750 is estimated to be 2.3 W/m^2 (IPCC, 2013c, pp. 13-14).

When others use these terms differently, in general, I will not point out the difference.

Theoretical Framework: Postcarbonism

> The stakes, for all life on the planet, surpass those of any previous crisis. The greatest danger is continued ignorance and denial, which could make tragic consequences unavoidable.
>
> – James Hansen and colleagues (2008, p. 17)

Scientific journals are noted for their staid rhetoric, but climatologists frequently use words like 'crisis' and 'tragic', along with 'catastrophe', 'disaster' and 'urgent'. We are living through the early stages of an epoch of change unlike any in human history[4] and which "is unprecedented in Earth's history" (Kiehl, 2011). This epoch was initiated by human activity, and humans are still the dominant force acting to change the global environment (Barnosky et al., 2011, 2012). Still, the process of change has a momentum of its own, and it cannot be understood, mitigated, or adapted to unless we understand human civilization and the global environment as parts of a single complex system. Given the complexity and diversity of the expected impacts of global environmental change, all sectors of society have to play a role in mitigating and adapting to the challenge. In particular, academics–in both the social and natural sciences–have a special responsibility to offer new ways to think about how human beings can survive and thrive on a rapidly changing planet.

The climate cannot be understood in isolation from the rest of the natural and social world. From a natural science perspective, the climate interacts with glaciers, oceans, ecosystems and cities in myriad and complex ways. From a social science perspective, the climate interacts with politics, human migration and urbanization, deforestation, overfishing, aquifer depletion, and nuclear proliferation. Each of these natural and human systems is complex on its own, and each feeds back on the climate and on each other in ways that are far too complex for any human being to fully comprehend, but which can be illuminated within a theoretical framework that transcends the divisions between the natural and social sciences.

[4] I am assuming the traditional demarcation between pre-history and history at the invention of writing. Writing was invented around 4000 years after the start of the Holocene, an epoch of remarkable climatic stability. Although the Geological Society of London has yet to officially determine that the Holocene has ended, I expect they will do so within the next ten years. I question the related movement to call the present time-period the 'Anthopocene'. Normally, transitional times are identified as 'Events' such as the 'End Permian Event' or the 'K-T Boundary Event'. I will refer to the 'Anthropocene' in this dissertation, and merely note that the usage is contested.

In this section, I will point the reader's attention to an emerging research paradigm that I am calling 'postcarbonism'. I will start by defining postcarbonism and will then summarize four interrelated aspects of postcarbonism – 1) a focus on adaptive mitigation, 2) a critical stance towards industrial capitalism, 3) a transdisciplinary approach towards research, and 4) a focus on systems and systems dynamics. Each of these will be discussed in turn, and I will then compare and contrast postcarbonism to other critical traditions.

What is Postcarbonism?

> 1. If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity.
>
> 2. It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future.
>
> -- *The Limits to Growth* (1972, p. 1)

I understand postcarbonism to be *a social, political, and intellectual movement that strives for radically prudent action in a changing and uncertain world*.

The term 'radically prudent' might seem like an oxymoron, but two contrasting examples will clarify. It would be prudent to avoid actions that might simultaneously create billions of refugees and open up an entire ocean as a new zone of great-power rivalry, thereby destabilizing a world in which there are more than 5 gigatons of nuclear weapons armed and ready to launch at a moment's notice (Kristensen & Norris, 2012a, 2012b). At the end *An Inconvenient Truth* (Guggenheim, 2006), Al Gore advised viewers to take a number of *moderately* prudent actions such as changing their lightbulbs. Hansen and colleagues (2008) advised *radically* prudent action–shuttering almost every coal-fired plant in the world by 2040–as a first step.

In the beginning was…

The word postcarbonism[5] is likely to cause some confusion. The *post-* is postcarbonism is both an aspiration and a pun. In 2012, humans released an estimated 9.7 billion tonnes[6] of carbon into the air (Peters et al., 2013). Postcarbonists *aspire* to a future when we will no longer engage in reckless behavior on such a massive scale. We do not live in a postcarbonist society, and to imagine that postcarbonist thinking can thrive within a society that is hooked on carbon is as delusional as describing the thinking of a heavy drinker who hopes to quit drinking someday as 'postalcoholism'. The name is a pun on postmodernism, poststructuralism, postcolonialism, etc. As I understand postcarbonism, it has little to do with any of these. The 'post-' traditions grow out of continental philosophy's rejection of scientism, but postcarbonism relies on science to help us understand the problems we face. Climatology is a rapidly changing science, and postcarbonist scholars may need to read and understand a large volume of peer-reviewed scientific research to stay on top of the field.

Humanity and the planet face a crisis, and we are unlikely to thrive (and may not survive) over the next one hundred years unless we make dramatic changes in how we

[5] I am not the first person to use "postcarbonism" in print. The Post Carbon Institute, a think tank in Santa Rosa, CA, has been working since 2003 (Heinburg & Lerch, 2010), and John Urry (2011) used the hyphenated word "post-carbonism" in passing (p. 86), and a number of book reviews used the unhyphenated word in their reviews (e.g. Bohr, 2013).
[6] I use the British spelling to indicate metric tons.

think about ourselves and our place on the planet. I cannot see a clear path forward at this juncture. My goal in describing this framework is to give a name to the problem, and to suggest my own thoughts on the question: What is postcarbonism? I invite readers to ask themselves what 'postcarbonism' means to them, to suggest their own answers, and to take steps towards building a postcarbonist society.

Focus on Adaptive Mitigation.

The United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC) treat 'adaptation' and 'mitigation' as distinct processes. In the next chapter, I will argue that the UNFCCC has largely failed to mitigate climate change. Its adaptation efforts have been no more successful. The UNFCCC Adaptation Fund is underfunded by around 3 orders of magnitude (compare Parry, et al., 2010 with "About the Adaptation Fund", 2011), and negotiations to adequately fund adaptation are largely stalled. While it would be foolhardy to abandon efforts to find a global solution that treats adaptation and mitigation as distinct processes, individuals may be more effective by working in their local communities to enact adaptive mitigation strategies.

'Adaptive mitigation' refers to climate management activities that simultaneously mitigate global climate change while adapting to local and regional climate change (Stone, 2012).[7] For example, students thinking about adaptive mitigation might research heat-tolerant tree species and then might work with the school's staff to plant those trees on the school grounds, thereby cooling the local climate while removing CO_2 from the

[7] Stone defines adaptive-mitigation strategies as, "climate management activities designed to reduce the global greenhouse effect, through control of gaseous and/or land-surface drivers, while producing regional climate-related benefits in the form of heat management, flood management, enhanced agricultural resilience, or other adaptive benefits" (p. 147).

global atmosphere. Of course, planting trees in a schoolyard does almost nothing to deal with global climate change–it barely impacts climate change in the school's immediate neighborhood. Embracing adaptive mitigation means recognizing that even though climate change is a global problem, no global solution will be found. Instead communities must embrace piecemeal efforts that: 1) aim to achieve multiple goals, 2) will fall short of achieving any of them, and 3) will still benefit local communities without harming the global environment.

Critique of capitalism

The critique of capitalism has been an important part of the social sciences since at least the 19th Century, but it has been rare, if not completely absent, from the natural sciences until recently. This is no longer the case. Costanza (2009) wrote this in *Nature*:

> Neither socialism, in which most property is common, nor capitalism, in which most is private, have dealt adequately with the open-access commons […]. The meltdown of these economic systems presents the opportunity to find a new balance that will help us lay the path to sustainable prosperity. (p. 1108)

Remarkably, Constanza believed that *Nature*'s readers would accept his assumption that capitalism was in "meltdown". More remarkably, *Nature's* editors either didn't question it, or they considered it and decided to let it stand.

The Post Carbon Institute has encouraged the discussion of "Post Carbon Economics", and "Ecological Economics" (see Farley, 2010). The emergence of ecological economics points to another aspect of postcarbonism: Postcarbonists understand humanity and nature as part of a single system, and seek to transcend traditional disciplinary boundaries, particularly the distinction between the natural and social sciences (see also Wilson, 1998).

Transdisciplinary research

Choi and Pak (2006) noted that the terms “interdisciplinary” “multidisciplinary” and “transdisciplinary” are often used interchangeably and sought to resolve the “terminological quagmire” by reviewing how each term has been defined and used by various sources. While recognizing that each term is used in many ways, they proposed that the terms refer to variations along a continuum. In multidisciplinary research, researchers in multiple disciplines work on a problem “in parallel […] without challenging disciplinary boundaries”. Interdisciplinary research involves active dialogue between disciplines that blurs the disciplinary boundaries, and sometimes creates new disciplines (such as biochemistry). “Transdiciplinary [research] involves scientists from many disciplines as well as non-scientists and other stakeholders, and […] transcends (hence ‘trans’) the disciplinary boundaries to look at the dynamics of whole systems in a holistic way” (p. 359).

The transdisciplinary effort to unite the social and natural sciences to address the current world crisis forces researchers to look at systems. The field of systems dynamics focuses on how systems behave and sometimes change over time, and is especially relevant to climate change. In the next section, I will introduce readers to the basics of system dynamics, by describing a rudimentary model of the climate.

Systems and System Dynamics.

> You think because you understand 'one' you must also understand 'two', because one and one make two. But you must also understand 'and'.
>
> – Attributed to Rumi

Meadows (2008) defined a system as "an interconnected set of elements that is coherently organized in a way that achieves [some function]" (p. 11). The human body is a system; so are a university, a nation, industrial capitalism, and the Earth. Many of the properties of a system are not present in the system's elements but emerge from the interactions of those elements. You can often learn more about the function of a system by looking at the structure of the interactions than by looking at the elements of the system.

A complex system can give rise to an entirely different system with very little change in the elements making up the system: Nations at peace can give rise to nations at war, and ice ages can give rise to ice-free planets. Systems can transform very slowly or very rapidly. The change in the Earth's ecosystem marked by the extinction of the dinosaurs occurred quite suddenly (Schulte et al., 2010), while the end-Permian event, which witnessed the extinction of around 80% of the world's animal species, unfolded over millions of years (Chen & Benton, 2012). The current extinction is unfolding much faster than the end-Permian event, though it is analogous in that both extinctions seem to involve global warming initiated by the burning of coal and petroleum (Payne & Clapham, 2012; Svenson et al, 2009).

The Climate System.

Given the importance of the climate to postcarbonist thinking, and the fact that some readers may not be schooled in the basics of climatology, I will use the climate as a model system to introduce basic concepts in systems dynamics.[8] The earth's climate system includes–among other elements–ocean currents, wind, and rain. These elements are interconnected; and together they function to transform light coming from the sun into infrared radiation that flows all directions into space.[9] Systems are modeled using stock and flow diagrams such as Figure 1. Stocks are the basic elements of a system, anything that you can see, hear, measure or count, like the stock of grain in a granary or the stock of money in a bank account. The Earth's surface contains a stock of heat, which is represented as a box in Figure 1. Heat can flow into the stock, which will tend to warm the planet, and heat can flow out of the stock, which will tend to cool the planet. The flows are represented as arrows. The rate at which heat flows in or out of the system can change over time, and the changing rate of flow is represented by the valves.

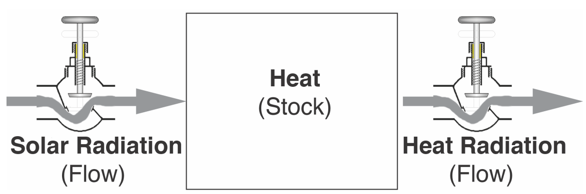

FIGURE 1
A very simple stock and flow diagram of the Earth's climate.

[8] Much of the material in this section is common knowledge among climatologists and students of systems dynamics, and will therefore be presented without citations. Readers who are interested in more detail can follow up with Meadows (2008), Kitchen (2013), or Smith (2012), especially lectures 5 and 6.

[9] Most climate scientists say the climate transfers heat from the tropics to the poles. This is a major function of the climate system. But, as the Earth spins, it transfers heat from the sunny side to the dark side, and the day-night cycle is an important part of the climate system. My framing will also allow me to build my argument.

So the Earth's surface is heated by solar radiation, and it cools by emitting heat radiation in to space. Figure 2 elaborates on this simple stock and flow diagram. As the Earth's temperature increases, it radiates more heat into space, and as it cools, it radiates less heat. The virtuous feedback between the Earth's temperature and the rate of heat flow from the Earth tends to stabilize the climate, and is therefore called a 'balancing' or 'stabilizing' feedback. Balancing feedbacks are also common in social systems. Within capitalism for example, price feeds back on both supply and demand to stabilize stocks of goods and services available in an economy.

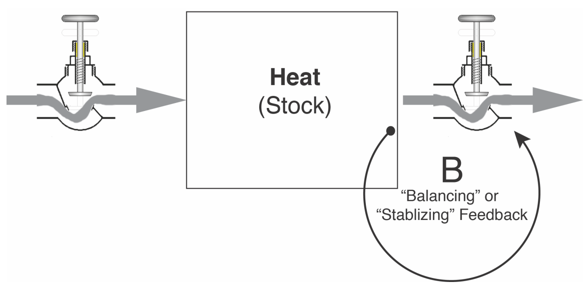

FIGURE 2
A stock and flow diagram including a balancing feedback

This model, which does not account for the oceans or the atmosphere, provides a surprisingly accurate estimate of the Earth's average temperature. If you make a set of simplifying assumptions, including that the Earth is a spherical 'black body' of uniform temperature, then you can make a relatively simple calculation and determine that the Earth's temperature 'should' be 252 K (-6°F), which is surprisingly close to the Earth's actual average temperature of 288 K (59°F).

The Earth is not a perfect black body; it has some 'whiteness'. A perfect black body absorbs all the light that hits it, and re-emits an equal amount of heat radiation. A perfect white body reflects all of the radiation that hits it, and isn't warmed by incoming light. 'Albedo' derives from the Latin word for whiteness, and scientists measure albedo on a scale from zero (for a perfect black body) to 100% (for a perfect white body). The open ocean's albedo is around 10%, forests have albedos ranging from 8 - 18%, bare rock is around 20%, sand is around 35%, and snow is around 65% (Barry & Chorley, 2003, pp. 324-328). As the Earth cools, snow and ice cover more of the planet. This increases the Earth's albedo, which lowers the amount of sunlight absorbed by the Earth, which cools the planet further, which leads to more ice, etc. This vicious cycle can be quite powerful, and geologists believe that the Earth has experienced three Snowball Earth events, in which the Earth was almost completely covered with ice. Luckily, it seems a slower balancing feedback involving CO_2 ended the Snowball Earth events (Maher, 2014). Figure 3 includes the ice-albedo feedback, which is notated with an 'R' for 'Reinforcing Feedback'.

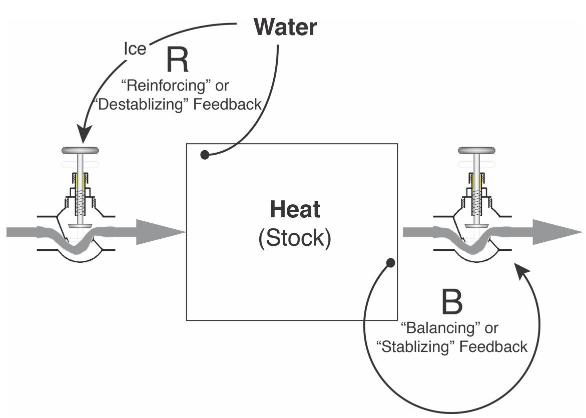

FIGURE 3
A stock and flow diagram including a reinforcing feedback

The Earth also has an atmosphere. Clouds have high albedo and can prevent light from reaching the Earth's surface, but they also prevent heat from radiating from the Earth. Even before condensing into clouds, water vapor is a powerful greenhouse gas, which lets sunlight pass through the atmosphere, but blocks heat radiation from leaving the Earth. As the planet warms, the amount of water vapor in the atmosphere increases, which blocks the flow of heat away from the Earth, which tends to warm the planet more. The water vapor feedback is another source of instability in the climate system, and is illustrated in Figure 4.

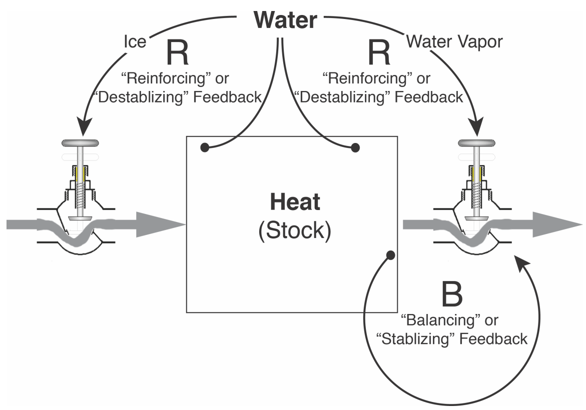

FIGURE 4
A stock and flow diagram including the ice-albedo and water vapor feedbacks.

Balance and imbalance in nature and society.

A common myth asserts that there is balance in nature. The reality is that natural systems include both balancing and reinforcing feedbacks. The reinforcing feedbacks create natural imbalances, which can give rise to runaway processes. Even if humans were to stop emitting carbon dioxide into the atmosphere, natural feedbacks would continue the process of climate change. But humans are unlikely to stop emitting carbon dioxide any time soon. In fact, the flow of carbon into the atmosphere may accelerate, largely because of a reinforcing feedback with a social system–namely capitalism.

The Capitalist System.

In the last several centuries, capitalism has come to dominate society and nature. Figure 5 is a very simple model of capitalism.

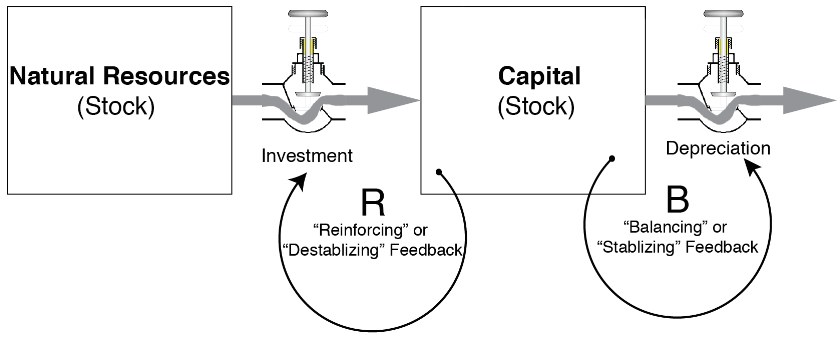

FIGURE 5
A simple model of capitalism

Any complex system includes many stocks and flows, but capital is an especially important stock within capitalism. Capital is defined as 'resources that are used for the production of goods and services'. Capital stocks include machinery and other productive resources. Natural resources normally need to be modified by human labor before they become capital, so a tree is not capital, but wood is.[10] Capital stocks depreciate over time, and the absolute rate of depreciation increases with the size of the stock, so this is a balancing feedback. A more interesting feedback involves the transformation of natural resources into capital stock. Capital is invested in the production of capital resources, which increases the stock of capital, which makes more resources available for investment, etc. This reinforcing feedback has generated stunning increases in both production and accumulated wealth during the capitalist era, especially

[10] Sometimes this modification can be very minor. Oil reserves under the Arctic Ocean are not capital. Absent a major social transformation, as Arctic sea ice melts, lawyers will labor to convert Arctic oil reserves into capital assets for specific capitalist enterprises, thereby opening them up for further capitalist exploitation.

since the emergence of industrial capitalism. At the same time, an increasing fraction of the world's natural resources have been consumed by capitalist production.

One of the tragedies of late-20th century capitalism was that rather than using the productive capabilities of capitalism to meet the needs of the poor, the system produced a lot of wasteful consumption in wealthy societies–partly by using human resources of creativity though systems of media and advertising to create desires for products that fail to satisfy any important human need. Figure 6 illustrates the role of marketing and wasteful consumption within modern capitalism.

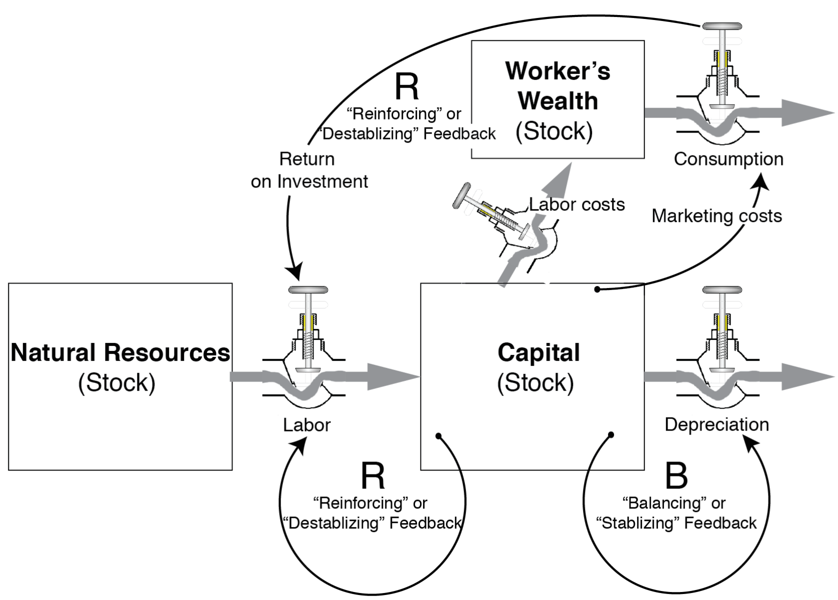

FIGURE 6
A less simple model of capitalism highlighting the role of wasteful consumption in modern capitalism.

Many wealthy and middle class people see that the system they are living in is destroying the natural systems on which life depends, and recognize that they are individually engaged in wasteful consumption. They therefore seek to reduce their own wasteful consumption in an effort to mitigate the destruction of natural systems. The Buddha supposedly taught that desire is the cause of all suffering, and Aristotle (1925) was probably correct that moderation is the key to human happiness, so decreasing the desire for wasteful consumption seems likely to decrease suffering and increase happiness. *But it is unlikely to deal with the problem of the capitalist destruction of nature.* If reduced individual consumption leads to an increased production of capital goods (or military hardware), then reducing individual consumption might exacerbate the underlying problem, which is the reinforcing feedback generated by the investment of capital to create more capital.

Systems often behave in counter-intuitive ways, and attempts to correct systems often exacerbate the underlying problems. The highly simplified stock and flow diagrams in Figures 5 and 6 don't capture the complexity or changing nature of capitalism, nor do they illustrate the many complex relationships between natural and social systems within the Earth system. Still, I hope this discussion gives the reader a glimpse of how systems dynamics can be used to understand nature, society, and their interconnections.

Addiction.

Meadows (2008) devotes a chapter of her book to describing a set of "systems traps". One of these, "Shifting the Burden to the Intervenor – Addiction" (pp. 131-135) is especially important to postcarbonist thinkers. Human society seems to be addicted to the consumption of natural resources–including fossil fuels. Even with the incredibly high levels of consumption seen in many developed capitalist societies, hundreds of millions of people continue to live in abject poverty, and many working people struggle to acquire the necessities of life.

Drug addicts and economies are complex systems with balancing feedbacks that act to maintain the overall state of the system in the face of external inputs. In the case of a heroin addict, the body adapts to heroin by lowering its production of natural opiates to maintain a relatively constant level of opiate in the body. In the case of capitalism, capital adapts to increasing wages by seeking low-wage workers in order to maximize its return on investment. (Moreover, the poor sometimes turn to capital markets to attain the necessities of life and find themselves needing to pay fees and interest on top of meeting the day to day expenses of living, which drives them deeper into poverty. This is a classic reinforcing loop, and is as much a facet of capitalism as the reinforcing loop involving investment and capital stocks.[11]) No matter how much wealth capitalism produces, processes internal to the system will produce classes of people who experience material hardship. Moreover, once the system adapts to the input–whether it be heroin or natural resources–it requires more of the input to maintain acceptable levels of well-being. If the process continues for long enough, the system may lose its ability to function without the external input: Capitalism has been consuming ever-increasing quantities of natural resources for over 250 years.

Addictions are very difficult to break, and ending an addiction often involves accepting short-term suffering for the long-term benefit of being relieved of the addiction. Any attempt to break society's addiction to increasing consumption of the Earth's natural resources will need to simultaneously address the underlying causes of poverty, or it is likely to exacerbate the suffering of the poor, and could spark a withdrawal crisis. Hansen's (2009) proposed revenue-neutral fee on carbon fails to address the underlying problem of the capitalist destruction of nature, but it may benefit

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[11] Within capitalist economies, income and wealth distributions follow a Pareto distribution–what is popularly known as the 80:20 rule, though in general it could also be known as the 70:30 or 95:5 rule. The Pareto distribution is widely seen in nature and society, and can emerge from reinforcing feedbacks in dynamic systems (Chernavskii, Nikitin, & Chernavskaya, 2008).

the poor financially, while lowering the consumption of fossil fuels. This is likely to reduce the suffering inherent in any process of addiction withdrawal and may forestall a climate crisis long enough for humanity to deal with larger systematic problems that are producing the current mass extinction.

Capitalism only functions when investors expect a return on their investment. If capital stocks are not growing, the economy can no longer be considered capitalist. In fact, if capital stocks don't grow at an accelerating rate (i.e. if productivity doesn't grow), then the economy enters a recession, which can cause material hardship for large numbers of people. The current mass extinction will not start to taper off until humanity ceases to undermine the natural systems on which life depends. Capitalism requires the transformation of natural resources into capital resources at a constantly accelerating rate; it may therefore be incompatible with ending the current mass extinction.

Postcarbonist scholarship appears in many guises. Researchers who want to gain familiarity with climate science can follow *Nature: Climate Change*, *Climatic Change*, and *Global Environmental Change*. Researchers working in the critical traditions may want to reexamine the roots of those traditions by looking at the writings of Marxist scholar John Bellamy Foster (e.g. Foster, 2000, 2013), who argues that Marx was deeply concerned with the "metabolic rift" between humanity and nature. Ecohealth is an emerging postcarbonist discipline that merges ecology, human health, and veterinary medicine in the context of ecological crisis. Charron (2012a; 2012b) reflected on the discipline's recent maturity. His reflections are informative for anyone interested in how an emerging theory and discipline can serve society and nature in a time of uncertainty and deepening crisis.

Postcarbonism and Critical Theory

> Labor is, first of all, a process between man and nature, a process by which man, through his own actions, mediates, regulates, and controls the metabolism between himself and nature. He confronts the materials of nature as a force of nature. He sets in motion the natural forces which belong to his own body, his arms, legs, head and hands, and in order to appropriate the materials of nature in a from adapted to his own needs. Through this movement he acts upon external nature and changes it, and in this way he simultaneously changes his own nature.
>
> – Karl Marx, *Capital* (1867/1976, p. 283)

Human beings are a part of nature, and our interactions with the external world shape both the world and ourselves. Foster (2011) argued that Marxist conceptions of the dialectical relationship between man and nature were central to Marx's theory of dialectical materialism. In particular, capitalist laborers are alienated from the fruits of their labor, largely because they lack access to the natural resources and tools needed to labor independently from the owners of capital. The alienation of man and nature is a historical process: 1) It started with the forced removal of European peasants from the land, which allowed the primitive accumulation of capital during the birth of the capitalist system; 2) Its full brutality became clear in simultaneous acts of genocide and enslavement as capitalism spread to America; and 3) It continues to this day. The alienation of man from nature also underlies many of today's environmental problems.

20th century critical theorists were rarely as pointed or insightful as Marx, but like Marx (1845), they understood, "Philosophers have only interpreted the world in certain ways, the point is to change it". Many scholars have applied the insights of critical theory to the environmental crisis, and this has given rise to two distinct but overlapping frameworks: Environmental justice and Ecojustice. While I sympathize with both, I cannot fully embrace either.

Environmental Justice

The environmental justice framework is primarily concerned with how environmental destruction disproportionately impacts poor and disenfranchised members of the living human community. Habermas's (2009) comment about the global economic crisis applies to climate change also:

> What worries me the most is the scandalous social injustice that the most vulnerable social groups will have to bear the brunt of the socialized costs for the market failure. The mass of those who are, in any case, not among the winners of globalization now have to pick up the tab for the impacts of a predictable dysfunction […]. Unlike the shareholders, they will not pay in money values but in the hard currency of their daily existence. Viewed in global terms, this avenging fate is also afflicting the economically weakest countries. (p. 184)

Individual or community vulnerability to environmental stress is related both to the nature and magnitude of the stress and to socioeconomic issues, including distribution of power within society (Adger, 2006). The least powerful members of any society are among the most vulnerable to climate change. The community of nations suffers from the same inequalities as other human communities. The small island states are among the least powerful nations on Earth, and–even if the world's nations achieve their stated goal of keeping warming below 2°C–many small island states may be wiped off the face of the earth (Alliance of Small Island States, 2010).

Justice is a difficult concept to define, and the question the just distribution of social responsibilities (including the responsibility to labor) and goods (including the products of human labor) is highly contentious. Capitalism's defenders argue that if individuals seek to acquire as many goods as possible, while taking on only those responsibilities that free will and circumstance require, then the market will create abundant goods and distribute them so that even the poorest human beings will benefit; some defenders of capitalism argue that any actions taken to create a more equitable distribution of goods and responsibilities will likely undermine the work of the free market's metaphorical 'invisible hand'. Their opponents argue that social goods and responsibilities should be distributed evenly among all people to the degree that they are able to take on the responsibilities and in need of the goods; some suspect that the 'invisible hand' and 'free market' are little more than myths.

As I understand it, the environmental justice movement embraces this second conception of justice. Still, climate change raises issues that go beyond the traditional concern for equity within the living human community. Issues of intergenerational justice come to the fore, and are especially salient for educators. The living enjoy infinitely more power and have infinitely greater responsibility than the unborn. Every human being alive owes it to future generations to take responsibility for climate change. Whatever good might come of such responsible action would benefit all future humans–poor and rich, black and white, disempowered and powerful.

Ecojustice

Scholars working in the Ecojustice framework often discuss environmental justice, but they also advocate justice for non-human animals, plants, and ecosystems. Sometimes this concern is framed by a deep ethic of caring for animals and the environment as when Martusewicz (2005) argued for need to encourage the development of “eco erosic love” in students (p. 331). Other writers evidence a lack of concern for human well-being, as when Mueller (2009) acknowledged the near-term possibility of human extinction, but argued that this isn’t an ecological crisis and that to consider it a crisis represented “anthropocentrism”.

But ecojustice is more than the collective sentiments of its advocates–it is a theoretical perspective. Many writers focus their research on discourse analysis and often advocate for a variety of subtly distinct framings of ecojustice (e.g. Bowers, 2002, 2005, 2010; McLaren & Houston, 2005; Mueller, 2009). Ecojustice is still an emerging theoretical perspective, so it’s not surprising that scholars might argue for one or another understanding of the perspective. But as an outsider, this aspect of the discourse within ecojustice strikes me as pointless and overheated.

Martusewicz and colleagues (2010) argued for the need for science teachers to address the “immense power, beauty, and wisdom” of the world by acknowledging its “mysteries” and engaging with the “sacred” (p. 11). This came close to advocating religious instruction in science class. Seven years earlier, Martusewicz (2003) wrote against “religious imposition in public schools” while approving of the Supreme Court’s ruling in Sante Fe v. Doe (which forbid *student-led* prayer during *after-school* activities). Reading the 2010 article, it was unclear whether she changed her position on student-led prayer. I suspect that she may still be troubled by traditional religious activity, including formal prayer, while she sees fewer problems with promoting her own, presumably more liberal, view of the sacred during science class.

The 2010 article also revealed a lack of understanding of basic scientific vocabulary. After arguing for a definition of " 'ecology' that goes beyond the limited view [established by science]", the authors defined "ecosystems" as "complex communities of life" (p. 12). Ironically this is a *more limited* definition than the traditional scientific definition of 'ecosystem', which includes not only "complex communities of life" but also the nonliving environment. They didn't explain why they excluded nonliving components from their definition of ecosystem, and I suspect one or both of two possibilities: 1) They were unaware of a definition of 'ecosystem' that could be found in any middle school life science text, or 2) As part of their sacred vision, they see ecosystem components like water and air as mystically 'alive'.

As social scientists, Martusewicz and her colleagues may not have given much thought to the distinctions between life and non-life or between communities and ecosystems, but I was surprised by an equally unconventional use of terminology from the social sciences. Much of the article critiqued a set of deeply ingrained discursive patterns, which they argued go back to the Enlightenment. In the penultimate paragraph of the article, they explained that in their perspective, the Enlightenment lasted from the 15^{th} to 18^{th} centuries. Middle school textbooks restrict the Enlightenment to the late-17^{th} and 18^{th} centuries. While any definition of historical eras must be arbitrary, I was left wondering why the authors weren't clearer from the start that they see the Enlightenment as starting hundreds of years earlier than most scholars. It's hard to imagine that they weren't aware that many of their readers associate the Enlightenment with the 18th century. It seems more likely that they were not really concerned with the Enlightenment as traditionally understood. Instead, I suspect they were critiquing scientific discourse, and were adopting a counter-Enlightenment (Berlin, 1968/1997, 1990; Garrard, 2006) discourse to speak about the scientific revolution that started in the 15th century and continues to this day. The use of counter-Enlightenment discourse to critique science troubles me. First, the counter-Enlightenment is linked to: 1) the support of monarchy in the 18th century, 2) reactionary anti-democratic movements in the 19th century, 3) 20th century fascism, and 4) radical 21st century capitalism as advanced by the followers of Ayn Rand (see Robin, 2011). Second, if it weren't for the hard work of thousands of scientists, we would be completely ignorant of the fact that the climate is changing, our role in the process, or how we might avert a catastrophe. The counter-Enlightenment critique of science could easily be used by climate change deniers, just as anti-evolutionists have adopted postmodernism in their attack on science education (see Pennock, 2010).

I cannot embrace ecojustice. First, I have not been impressed by the quality of what I have read. Second, I embrace reason and defend science, and I have yet to see any writers operating within an ecojustice framework who would take a similar stance.

Finally, I am much more concerned with the wellbeing of humans than I am the welfare of polar bears, penguins, or plasmodia, though I can sympathize with those who want to expand the sphere of moral consideration to include such creatures. If you embrace Bentham's notion that ethical actors should strive to increase pleasure and decrease pain, I suspect that polar bears and penguins can experience both pleasure and pain, and are therefore worthy of our moral consideration. On the other hand, I am not convinced that any non-human animals, even very large-brained creatures such as cetaceans or giant squid, strive after meaning and purpose in life.[12] So under my proposed maxim, they deserve significantly less moral consideration than do human beings. Of course, I may be mistaken. Moreover, I recognize that some people find great meaning in alleviating the suffering of animals, plants, and even inanimate objects like the ocean, and I would never act to deprive those people of the opportunity to find meaning in their lives.

While I do not intend to focus on either an environmental justice or ecojustice framework, I see value in both frameworks. Critical theory informed my methodology, as I will discuss in more detail in Chapter 3.

Organization of the Rest of this Dissertation

This dissertation uses the standard five-chapter format, with one slight modification in chapters 4 and 5. Instead of including the cross case analysis in Chapter 4, it will be included in Chapter 5 to allow for the more elaborate discussion called for by the fact that I am attempting to describe a new theoretical framework while conducting my analysis.

Chapter 2 will be a literature review. It will start by reviewing the basics of climate science, and will then look at prior work related to each of my research questions.

Chapter 3 will discuss the research methodology, including research design, data collection, analysis, and representation. It will include a discussion of case studies, and will discuss how case studies might be conducted within a postcarbonist framewok.

[12] I am fairly convinced that the striving after meaning and purpose is a uniquely human trait. In fact, I highly doubt that any human beings sought lives rich in meaning and purpose until the emergence of Modern Human Behavior between 50-70,000 years ago. My thoughts on this matter go beyond the scope of this dissertation, and have been influenced by several readings (Becker, 1973; Green et al., 2010; Klein, 2009; Varki, 2009; Varki & Brower, 2013; Varki, Geschwind, & Eichler, 2008).

Chapter 4 will present the results of the research in the form of five individual case studies: three high school teachers, one middle school teacher, and one elementary school teacher. Each case will be dealt with separately, but readers will note certain similarities and differences between the cases. In each case, I will assert that a teacher's most valuable resources are his or her own skill, knowledge, and personality.

Chapter 5 will present a cross case analysis and discuss the study's implications. Particular attention will be paid to how postcarbonism informed my analysis.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Teacher practices around climate change have not been extensively researched. A search of five EBSCO databases[13] for uses of the subject terms 'climate change' and 'teach*' returned only 24 results, most of which are not relevant to this study. Searches on the publisher's website for both *Science Education* and the *Journal of Research into Science Teaching* using the phrase 'climate change' in any field returned a total of 111 articles. Most of these articles had a single passing mention of climate change.

This chapter will start with a review of climate science. Given my postcarbonist stance that the climate and society should be understood as two parts of the same system, I will also discuss actions by the international community to address climate change and climate scientists' views on the likely effectiveness of those actions. Then, I will discuss each of my five research questions, while giving special attention to writings that align with my understanding of postcarbonism.

Climate Science

> Thus the atmosphere admits of the entrance of solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet.
>
> – John Tyndall (1859/1862, p. 158)

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[13] Academic Search Complete, Education Research Complete, Educational Administration Abstracts, ERIC, and Family & Society Studies Worldwide.

The physics of the greenhouse effect have been well understood for over 150 years, and most science educators are familiar with basic climate change science. This review will elaborate on the basic understanding by focusing on forcings and feedbacks.

Forcings

In the previous chapter I defined 'radiative forcings' as, "The change in energy flux caused by a driver (such as CO_2 or black soot) calculated at the tropopause. The best current estimate of total anthropogenic radiative forcing since 1750 is 2.3 W/m^2 (IPCC, 2013c, pp. 13-14)". Some readers may require a clearer explanation. 'Energy flux' is the rate at which energy flows through some surface, and is measured in Watts per square meter (W/m^2). The rate at which energy flows from the sun to the Earth measured at the top of the atmosphere when the sun is directly overhead ('the solar constant') averages around 1361 W/m^2, but it varies because of the solar cycle and other natural processes by around 1.3 W/m^2. When the sun brightens, the flow of energy to the Earth's surface increases, and the atmosphere tends to warm; the opposite happens when the sun dims. The change in how much solar energy flows towards the Earth is called the solar forcing. But the maximum solar forcing is less than 1.3 W/m^2. Radiative forcings are measured for an average square meter on the Earth's surface, whereas changes in solar intensity are measured with the sun directly overhead. Moreover, clouds, snow, and other substances reflect about a third of the incoming sunlight back into space, and this lowers the effective dimming or brightening of the sun. Accounting for both of these factors yields a maximum solar forcing of around 0.23 W/m^2. This is about one-tenth of the estimated radiative forcing due to human impacts on the environment (See Figure 7).

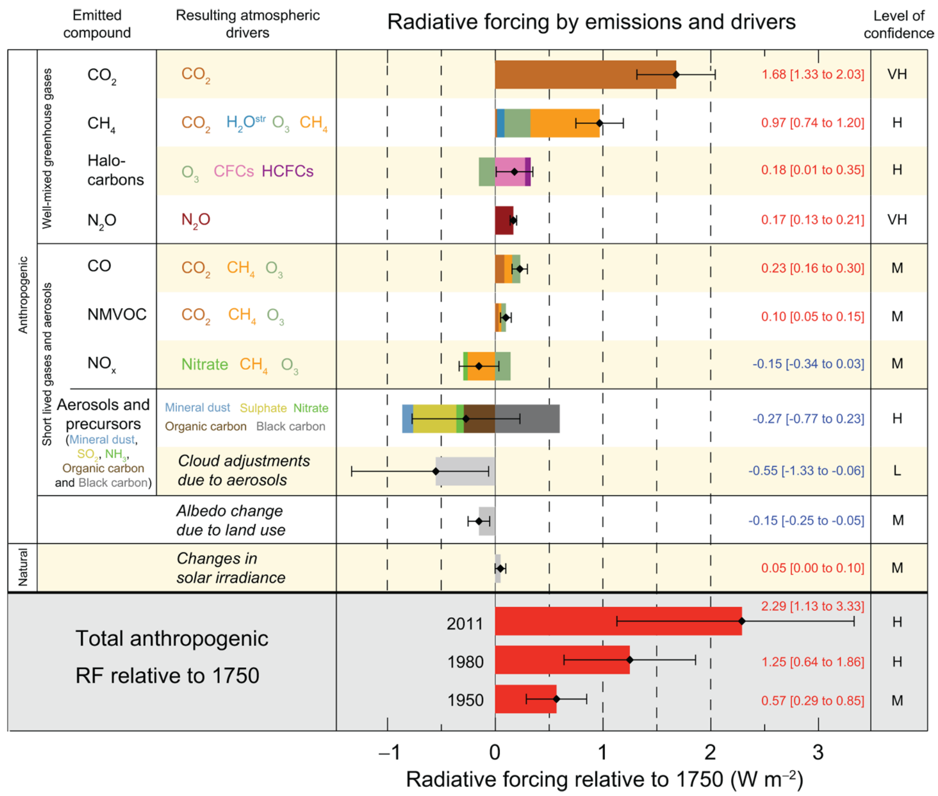


FIGURE 7
Anthropogenic and natural forcings since 1750. Note the solar forcing in the diagram is smaller than the forcing due to cyclic changes in solar intensity described in the text. Climate scientists believe that the sun has brightened slightly since 1750, and the solar forcing in the diagram refers to that smaller forcing (IPCC, 2013a, p. 688). Error bars represent 90% confidence intervals. Image from (IPCC, 2013c, p. 14).

Figure 7 merits close examination. Much of the public discussion of climate change focuses on the role of CO_2. The radiative forcing from CO_2 is less than half of the combined positive forcings, even though CO_2 gets much more than half the media coverage. Moreover, some human activities tend to cool the climate. Many of these negative forcings are short-lived, so if human impact on the climate were to stop right now, global warming would likely accelerate, at least in the short term. Finally water vapor is a very important greenhouse gas, but it is not considered a forcing–it is considered a feedback.

Feedbacks

As I noted in the previous chapter, feedbacks arise in all complex systems. The climate includes a number of positive and negative feedbacks. My earlier discussion of the water vapor feedback ignored a major complication. The presence of water vapor in the atmosphere encourages cloud formation. Clouds block sunlight during the day, and retain heat at night, but the net effect is cooling, and clouds therefore result in a balancing feedback. Still, the 'evaporation – water vapor – cloud' feedback–like other *fast feedbacks*–acts relatively quickly, and climate modelers have been able to refine their understanding of fast feedbacks by comparing their predictions to actual changes in the climate. Although clouds remain an area of active research, their role in the climate system is better understood than many other feedbacks.

Slow feedbacks are common. In the previous chapter, I discussed the ice-albedo feedback, but again I ignored a complication. The basic feedback is simple. As the planet warms, glaciers melt. Glaciers reflect sunlight back into space, so glaciers tend cool the planet, and the melting of glaciers represents a reinforcing feedback that tends to destabilize the climate. But global warming increases evaporation, which increases precipitation, and increased snowfall near the poles causes glaciers to grow. This tends to cool the planet, thereby stabilizing the climate system. Climate modelers try to account for negative and positive feedbacks involving the advance and retreat of glaciers, but as with other *slow feedbacks*, it is difficult to test and refine the models by comparing them with actual changes in climate.

Another set of slow feedbacks involves the effect of climate on terrestrial ecology. Phillips and colleagues (2009) argued that the Amazon jungle may be on the verge of ecosystem collapse, and could turn to grassland. They estimated that the conversion of biomass to CO_2 during the 2005 Amazonian drought added 1.2 –1.6 billion tonnes of carbon to the atmosphere and that the long-term effects of the drought may be even greater. Balshi and colleagues (2009) argued that climate change could increase the rate of fire in boreal forests, turning them from a carbon sink to a carbon source, with a potential net change in carbon storage of around 20 billion tonnes by 2100. Schaefer and colleagues (2011) argued that melting permafrost could stimulate the release of around 70 to 140 billion tonnes of carbon dioxide by 2100. Harvey (2012) argued that warming will lead to increased methane emissions from wetlands, which could add 5-15% to climate sensitivity. Finally, 99.9% of the Earth's carbon is stored in the lithosphere. Solid methyl hydrates that are currently stored in the deep ocean and under the permafrost could be released by global warming, and the pressure release resulting from the melting of ice sheets could discharge additional methane currently stored in rock (Kroeger, di Primio, & Horsfield, 2011).

Geologists believe that slow feedbacks drive major changes in the climate system, such as the ice ages of recent Earth history, or the complete loss of polar glaciers in the more distant past. After considering the potential impact of these and other slow feedbacks, Harvey (2012) concluded that by 2100 "global […] warming [might] render portions of the world currently occupied by over half of the human population to be uninhabitable by humans […] due to the periodic occurrence of 6-hour mean wet-bulb temperatures in excess of the practical physiological limit of 33°C" (p.139).[14]

[14] Wet bulb temperature is almost always lower than the more familiar dry bulb temperature. A wet bulb temperature of 33°C would be equivalent to 43°C (110°F) on a typically humid summer afternoon in Georgia, or 60°C (140°F) in the desert. A six-hour mean would imply peak temperatures in excess of these numbers.

Complicating the threat of uncontrolled and accelerating global warming is the fact that CO_2 forms an acid when it dissolves in seawater. The oceans are becoming acidic much faster than anyone anticipated (Kerr, 2012), and they are now more acidic than they've been in over two million years (Hoenisch, 2009). Acidification represents a major threat to marine ecosystems, and the combination of acidification and warming makes the global collapse of coral reef ecosystems likely, even assuming IPCC best-case scenarios for carbon emissions (Hoegh-Guldberg et al., 2007). Kump and colleagues (2010) analyzed ocean acidification within the context of the ocean's long history, and after considering a number of past events, including the Permian-Triassic extinction event and the post-snowball super-greenhouse, they concluded that if humans continue business-as-usual, we are "likely to leave a legacy of the Anthropocene as one of the most notable, if not cataclysmic, events in the history of our planet" (p. 106).

In book written for laypeople, James Hansen suggested at a more horrific possibility. Hansen started his career in planetary astronomy, specializing in Venus–a planet that most scientists believe had oceans before they boiled as a result of a runaway greenhouse effect. In *Storms of My Grandchildren* (2009), he wrote:

> [Might] Earth proceed to the Venus syndrome, a runaway greenhouse effect that would destroy all life on the planet, perhaps permanently? While that is difficult to say based on present information, I've come to conclude that if we burn all reserves of oil, gas, and coal, there is a substantial chance that we will initiate the runaway greenhouse. If we also burn the tar sands and tar shale, I believe the Venus syndrome is a dead certainty. (p.236)

Goldblatt and Watson (2012) made a convincing case that a runaway greenhouse is extremely unlikely to boil the oceans, but they could not rule out a “moist greenhouse” that would likely kill off most eubacteria and all eukaryotes.

Hansen and colleagues (2008) argued that we may have already passed a dangerous tipping point, beyond which climate change will accelerate without any additional forcings by human beings. Still, oceans and glaciers can absorb huge amounts of heat, and–to build on Hansen’s tipping metaphor–this provides a lot of inertia. If we can stabilize the system before it topples, then a disaster could be averted. But if the climate starts to topple, it would be impossible to halt the process. The tipping point likely resides between 350 and 550 ppm of atmospheric CO_2–which is currently between 390 and 400 ppm. We may have passed the tipping point, but because of the vast ‘inertia’ provided by the oceans and polar ice caps, we probably have not passed the point of no return. Still, social systems have their own inertia, and this may prevent timely action.

The Political Climate

In 1992, signatories to the UNFCCC bound themselves to “prevent dangerous anthropogenic interference with the climate system” (“United Nations Framework Convention on Climate Change,” 1992, p. 4). In 1992, dangerous climate change was almost certainly avoidable, but scientists now say that it is unavoidable. Today’s youth will need to adapt to the danger while striving to avert extreme danger.

“Dangerous anthropogenic interference”

Months before the UNFCCC 15^{th} Conference of Parties (COP 15) met in Copenhagen, Smith and colleagues (2009) published an article that would echo in the conference chambers. They stated that, in light of the UNFCCC’s language, assessing "danger" was "a value judgment that would be policy prescriptive […]" (p. 4133). Therefore, having used 'dangerous' in the paper's title, they discussed 'risks' in the text, and allowed readers to draw their own conclusions about 'dangers'. To help readers assess risk, they provided an updated version of the 'burning embers' graphic from the 2001 IPCC report (See Figure 8).

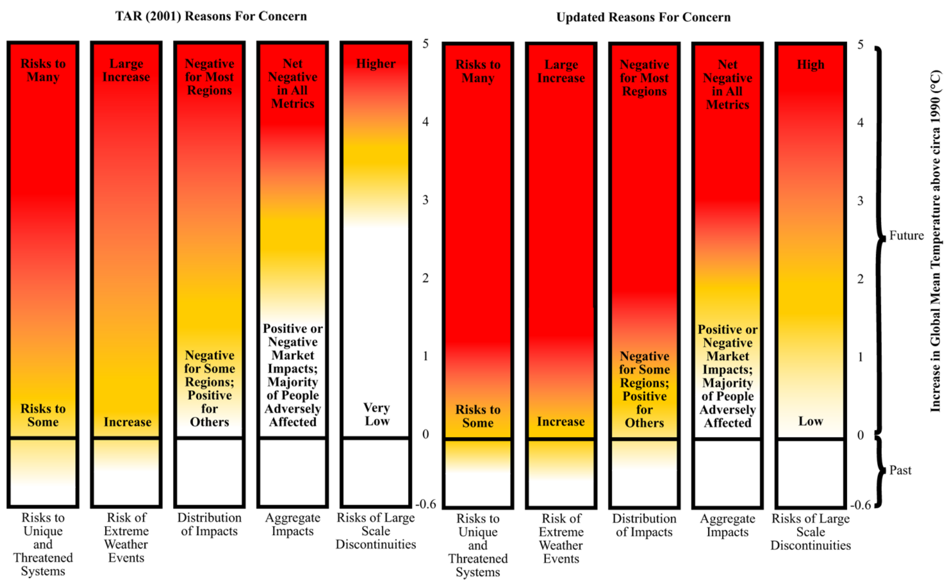


FIGURE 8
Updated burning embers diagram (Smith et al., 2009, p. 4134), showing the changing views of climate scientists concerning the risks associated with global warming. White represents "little to no risk", yellow represents "moderately significant risks", and red represents "substantial or severe risks". The graphic on the left shows the 2001 consensus, while the graphic on the right shows a 2009 assessment.

The updated graphic shows that even a 1°C temperature increase (over 1990 levels) is associated with 'significant', 'substantial', and possibly 'severe' risks. 2°C would soon gain international importance, and is associated with a number of 'moderate', 'substantial', and 'severe' risks. At 4°C the risks of large-scale discontinuities (such as the breakdown of thermohaline circulation, the deglaciation of Antarctica, or the release of large reserves of methane into the atmosphere) may be 'severe'.

Months after the paper was published, COP 15 met amidst strident calls by 42 island nations to limit warming to 1.5°C.[15] The Alliance of Small Island States (AOSIS) declared that climate change is "the most serious threat to our survival", and the President of Granada called the willing failure to meet the 1.5°C target "benign genocide" (AOSIS, 2009; Gardner, 2009). At the conference's conclusion, delegates representing 167 nations agreed to "hold the increase in global temperature below 2 degrees Celsius" (UNFCCC Conference of the Parties (COP), 2009, p. 5). A year later, in Cancún (COP 16), the assembled nations agreed to *self-imposed non-binding* emission targets which they hoped might keep warming below the 2°C target.

Less than three years later, the IPCC (2014b) stated with high confidence that, "the Cancún Pledges are not consistent with cost-effective long-term mitigation trajectories that are at least as likely as not to limit temperature change to 2°C" (IPCC, 2014b, pp. 15-16). One of the world's leading climate scientists, Kevin Anderson, was even less sanguine about the 2°C goal and the Cancún Pledges. He and Alice Bows (2011) argued that 2°C may represent the "threshold between 'dangerous' and 'extremely dangerous' climate change" (p. 20). Earlier Anderson had referred to the Cancún Pledges as "astrology" and wrote:

> There is currently nothing substantive to suggest we are heading for anything other that a 4°C rise in temperature, and possibly as early as the 2060s. Yet over a pint of ale or sharing a coffee it is

[15] Different communities use different baselines to discuss global warming. The UNFCCC references pre-industrial temperature, while the IPCC generally references 1990. Pre-industrial temperature was about 0.5°C below 1990 temperature. Careful readers are advised to focus on the IPCC estimates, as meteorological records from 1990 are more reliable than pre-industrial records. For consistency, readers might then subtract 0.5°C of warming from any discussion of the UNFCCC process. I will generally ignore the difference, as predicted warming is highly uncertain, and 0.5°C is within the margins of uncertainty.

hard to find any scientist seriously engaged in climate change who considers a 4°C rise within this century as anything other than catastrophic for both human society and ecosystems. Moreover, ask those same scientists if 4°C is likely to be as high as it could get prior to the temperature beginning to fall, and many will shake their heads pointing to a range of discontinuities (tipping points) that may see us witness temperatures increasing well beyond 4°C. (Anderson, 2010)

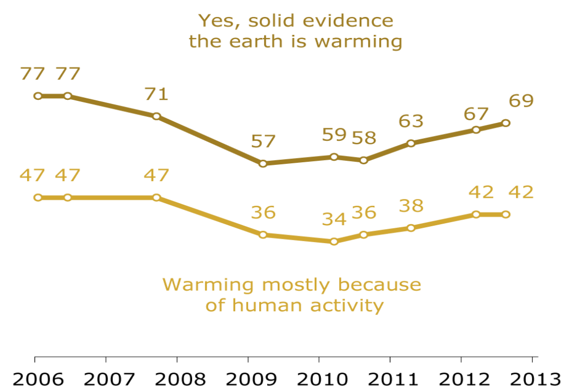
The substantial or severe risk of large-scale discontinuities makes it almost impossible to predict what might happen if the world approaches the 4°C threshold. The end of the Cenozoic is possible; the end of the Phanerozoic cannot be ruled out.

Disconnect between scientific and public assessment of the risk

The Pew Research Center (2013) found that US opinion about climate science is both in flux and deeply divided (see Figure 9). In particular, from the second graphic, you can infer that only 29% of survey respondents stated that the Earth is warming and that this warming is mostly because of human influence. This contrasts starkly with the IPCC (2013c) assessment that: 1) It is "very likely" (more than 90% certain) that human influence is the cause of each of a large number of observed changes in the climate system, and 2) It is "virtually certain" (more than 99% certainty) that a number of major impacts will be evident by the end of the 21st century. In short, over 70% of the U.S. public do not accept the scientific consensus on climate change. Moreover, fewer than 10% of self-identified Republicans accept the scientific consensus. Georgia residents probably resemble the rest of the U.S. public in this regard: Still, the dominance of the

Republican party among Georgia's elected officials means that the State is unlikely to take measures to address the challenge without a dramatic shift in public opinion.

Is There Solid Evidence the Earth is Warming?



PEW RESEARCH CENTER March 13-17, 2013.

Continuing Partisan Divide in Views about Global Warming

Solid evidence the earth is warming?	**Total** %	**Rep** %	**Dem** %	**Ind** %
Yes	69	44	87	69
Mostly because of …				
Human activity	42	19	57	43
Natural patterns	23	22	23	22
Don't know	4	3	7	4
No	27	50	10	28
Mixed evidence (Vol.)/ Don't know	5	7	3	4
	100	100	100	100

PEW RESEARCH CENTER March 13-17, 2013.
Figures may not add to 100% because of rounding.

FIGURE 9
Shifts and divisions in U.S. public opinion regarding climate science. By looking at the second graphic, you can infer that 50% of self-identified Democrats stated that there is solid evidence for global warming and that it is mostly because of human influence, while only 8% of Republicans held similar views. (Pew Research Center, 2013, p. 3)

Georgia's children will almost certainly inherit a dangerous world. Yet most of their parents and teachers underestimate the threat, and few Georgia politicians are willing to devote needed resources to address it. Still today's children may avert extremely dangerous climate change, and the next few decades will probably determine whether or not the current crisis devolves into the 6th great mass extinction. The crisis is partly a result of human ignorance, and teachers–in particular science teachers–have an important role to play in combatting ignorance about the climate.

Educational Research

The rest of this literature review will focus on my research questions, starting with 'What do teachers teach about climate change?' Educational researchers have paid scant attention to actual K-12 teacher practice around climate change. A very large number of researchers in science education (and many other fields) talk about what and how teachers *should* teach, and I will barely scratch the surface of this body of work.

What do teachers teach about climate change?

Berkman and Plutzer (2010, 2011) found that a majority of high school biology teachers are "cautious" when discussing evolution. Some teachers present both sides of the evolution controversy, including positions that lack any scientific merit. Wise (2010) reported the results of a 2007 survey of Colorado science teachers that hints that many Earth science teachers may take a similar approach to climate change education. Around 99% of Wise's respondents thought that Colorado students should learn about global warming in school, but fewer than half of these same teachers included lessons on climate change in their curriculum. In fact, only 65% of the *Earth science teachers* included formal lessons on climate change, and 8% failed to mention the topic at all. Eight out of ten earth science teachers in her survey agreed with the statement, "recent global warming is caused mostly by things people do", yet seven out of ten of these same teachers present the evidence on climate change with equal weights to both sides or in ways that would leave students unclear about the scientific consensus (pp. 300-302).

If some teachers navigate the controversy by compromising on scientific rigor, many teachers may simply pass their own misunderstandings on to their students. Many studies of pre-service and in-service teachers reveal widespread misunderstanding of climate science (e.g. Lambert, Lindgren, & Bleicher, 2011; Papadimitriou, 2004; Ratinen, Viiri, & Lehesvuori, 2013). In fact, if you compare these studies, with Shepardson et al.'s (2011) research on seventh graders, it seems that many teachers' conceptions of the climate system are not significantly more sophisticated than their students'. Boon (2010) directly compared teacher and student understandings of the climate in Queensland, Australia, and found that both groups expressed similar misconceptions. She suggested that Queensland's low performance on science assessments may involve a vicious cycle in which misinformed students grow up to become misinformed teachers who then misinform their students.

What teachers say they should teach about climate change.

Gayford (2002) met with four focus groups of 4-5 science teachers to discuss, "How should GCC [global climate change] be addressed in the science curriculum?" The groups met three times, and early in the process they changed the question to, "What contribution should the study of GCC make to the science curriculum?" The participants thought that science teachers are not responsible for solving major "problems of the day that were defeating experts" (p. 1195). They resisted the notion that they might collaborate with social studies educators in order to educate their students about the complex political and economic problems raised by climate change, and wanted to focus on the job of teaching the required science curriculum. This dissertation is premised on my convictions that: 1) Science teachers are experts with responsibility for addressing "major problems of the day", 2) Climate science needs to be understood at the intersection of the natural and social sciences, and 3) It is important to respect what teachers say. So Gayford's work points to a deep contradiction in my work. Gayford's study was published in 2002, and it reported on discussions that took place in 1998 and 1999. A lot has changed since then, but this may not resolve the contradiction.

Although Gayford's participants hesitated to take on new responsibilities, they thought that climate change might connect to a number of topics already in the curriculum, including the Nature of Science (NoS). Two research teams investigated how to combine NoS instruction with teaching about global warming. Khishfe and Lederman (2006) worked with two sections of a ninth grade environmental science class that were taught by the same teacher. Both sections received explicit NoS instruction during the same six-week period that they were studying global warming. In the "integrated" group, their teacher referenced climate change in their class discussions of NoS, but in the "control" group, the NoS instruction did not mention global warming. There were no significant differences between the two groups in outcome measures of either NoS or climate change, and therefore no reason to recommend either for or against the integration of NoS instruction into climate change content. Bell and colleagues (2011) had similar results in their study of NoS instruction in a science methods course for pre-service elementary school teachers. Four different classes experienced different instructional "treatments" according to a 2x2 matrix. Two classes received explicit NoS instruction, and two received instruction on climate change. While all groups benefitted from the instruction they received, there was no significant interaction. Instruction in NoS didn't improve understanding of content related to climate change, and instruction in climate change had no significant impact on NoS understanding. If, as Gayford's participants suggest, the goal of climate change instruction should be to help students understand NoS, it is unlikely to meet that goal. On the other hand, climate change instruction doesn't seem to impede NoS learning.

What scientists say teachers should teach about climate change.

Storms of My Grandchildren (Hansen, 2009), *Climate Change: The Science of Global Warming and Our Energy Future* (Mathez, 2009), and *Global Climate Change: Turning Knowledge into Action* (Kitchen, 2013) were all written by scientists for lay readers. They may offer insight into what scientists think educated citizens need to know about climate change. All three discussed basic concepts in climate science, such as feedbacks, climate forcing, climate sensitivity, paleoclimatology, and the carbon cycle. All three debunked climate change denial. All three discussed possible solutions to the climate crisis.

Somerville (2011) wrote as a scientist for an audience of scientists. He argued that dramatic action is needed within the next decade to avert a disaster, and concluded, "Realistically, there may be no chance to educate the general public in depth about the science so quickly" (p. 513). Given his pessimism about whether education can help avert a disaster, he turned his attention to combatting the "well-funded and effective professional disinformation campaign has been successful in sowing confusion" (p. 513), and offered six principles that the public may need to understand in lieu of a detailed understanding of climate science:

> 1. The essential findings of mainstream climate change science are firm. The world is warming. […]

2. The greenhouse effect is well understood. It is as real as gravity. […]

3. Our climate predictions are coming true. Many observed climate changes, like rising sea level, are occurring at the high end of the predicted range. Some observed changes, like melting sea ice, are happening faster than the anticipated worst case. Unless mankind takes strong steps to halt and reverse the rapid global increase of fossil fuel use and the other activities that cause climate change, and does so in a very few years, severe climate change is inevitable. Urgent action is needed if global warming is to be limited to moderate levels.

4. The standard skeptical arguments have been refuted many times over. […]

5. Science has its own high standards. […] People who are not experts, who are not trained and experienced in this field, who do not do research and publish it following standard scientific practice, are not doing science. […]

6. The leading scientific organizations of the world […] have carefully examined the results of climate science and endorsed these results. […] The first thing that the world needs to do to confront the challenge of climate change wisely is to learn about what science has discovered and accept it. […] (pp. 513-514)

Somerville despairs that the laypeople can understand climate science, and then asks them to accept it. The consensus view on evolution education is the exact opposite–that teachers should ask students to understand evolution and should not insist on acceptance (e.g. Smith & Siegel, 2004). While I share Somerville's sense of urgency and his frustration with climate change denial, I doubt that asserting the authority of climate science is sufficient to address the crisis or students' educational needs.

What educational researchers say teachers should teach about climate change.

Koulaidis and Christidou (1999) interviewed 40 Greek eleven- and twelve-year-olds to analyze their thinking about the greenhouse effect, and they recommended that teachers act to correct five common misconceptions. The first involved the "misconception" that the atmosphere is organized into layers, "some students view the different atmospheric gases as located in distinct layers, whereas they do not seem to conceptualize the uniform diffusion of the greenhouse gases in the atmosphere" (p. 570). (No doubt the authors meant to say, 'While many students understand that the atmosphere is organized into layers, they often do not understand that greenhouse gases are well-mixed within the troposphere'.) They also found the widely reported confusion of the greenhouse effect and ozone depletion. Two other misconceptions were related to infrared and ultraviolet radiation. Finally, they said that students needed to have a more elaborate understanding of the greenhouse effect, and needed to distinguish it from atmospheric pollution.

Mohan, Chen and Anderson (2009) developed "a learning progression for carbon cycling in socio-ecological systems" (p. 675) based on interviews with learners of varied ages. They identified four "Levels of Achievement" in student reasoning about processes that transform carbon. Level 4 Achievement included "[tracing] chemical substances through hierarchically organized systems" (p. 692). This struck me as vague, but they seemed to be saying that Level 4 thinkers could understand the carbon cycle by linking macroscopic and microscopic processes, for instance by linking weight loss after exercise with cellular respiration and the addition of CO_2 to the atmosphere. Very few high school students provided consistent Level 4 accounts, and the authors suggested that a majority of college students and science teachers were more likely to offer Level 3 responses that Level 4. The authors concluded by noting that *at least* Level 4 reasoning in needed to understand scientific arguments about global climate change. "We are asking the American public to consider profound changes in their lifestyles on the basis of arguments from scientific evidence, that according to our data, they cannot understand" (p. 694).

Bangay and Blum (2010) wrote "the challenges of climate change require all concerned to look to fundamentals and examine the degree to which existing educational provision is adapted to and prepares people for radically different futures" (p. 359). They argued that people need skills more than knowledge, and identified "critical thinking and problem solving" (p. 363) as key skills students need to develop. In a similar vein, Burandt and Barth (2010) argued that teachers should focus not on knowledge, but on competencies. They offered a model for undergraduate education that focuses on four main competencies: 1) the competency to analyze multiple, networked, complex problems, 2) the competency to deal with uncertainties and think proactively, 3) the competency to deal with different sets of information and knowledge, and 4) the competency to use knowledge to secure a capacity to act.

Steps towards postcarbonism.

Finley, Nam and Oughton (2011) called for greater attention to Earth Systems Science (ESS), which they defined as, “the study of natural and social systems and the interactions among these systems” (p. 1067). They pointed to the growing importance of ESS within the scientific and educational communities, and referenced the focus on systems within the Earth Science Literacy Principles (ESLP) (Earth Science Literacy Initiative, 2009). They went beyond the ESLP in two important respects: They saw systems as *the* central organizing principle for Earth science, and they called for including social systems within the ESS framework. Still, their discussion of systems was often vague. In particular, while they often discussed “change”, they never mentioned ‘system dynamics’, and they seemed to understand feedback loops differently than I do. They never defined ‘feedback’, but some of their statements–like “Some changes within and among systems are cyclic and thus have feedback loops” (p. 1073)–indicated that they understood feedback loops to be equivalent to the two-way flow between stocks. In contrast, Meadows (2008) defined a feedback as “when changes in a stock affect the flows into or out of that same stock” (p. 25). Their limited understanding of feedbacks fed into a limited understanding of systems. They proposed that “cyclic change” should be an “essential idea” within ESS, but the words ‘acyclic’, ‘nonlinear’, and ‘chaotic’ appeared nowhere in their text. They “[gave] only limited attention to the analysis of social systems” (p. 1067), and called for collaboration between science educators, social scientists, and social science educators in elaborating their framework. I fully agree, and I would add that any elaboration of ESS should also involve specialists in systems science.

What should teachers teach about climate science?

Varied experts and stakeholders express diverse and sometimes contradictory views, so it is not possible to reach any firm conclusions on what teachers should teach about climate change. Gaining a better understanding of what teachers currently teach may provide a basis for further discussion, and this study might therefore fill a void.

How do teachers teach about climate change?

I already mentioned that seven out of ten Colorado teachers in one survey reported that they teach both sides of the 'scientific' debate around climate change (Wise, 2010). Many teachers engage in argumentation when teaching climate science. Some teachers use inquiry. Others teachers engage in action research or other critical approaches to education.

The research reported on in this section consists almost entirely of researchers observing teachers while the teachers use methodologies developed by the researchers themselves. There is a very large void in understanding how teachers teach climate change when they are not involved in curriculum development projects.

Argumentation

McNeill and Pimentel (2010) looked at the argumentation practices of three science teachers as they presented a curriculum that had been developed by the research team. The research focused on the first class in a module on climate change that was designed to take 16-19 class periods to complete. The students watched two short videos on climate change: One presented the scientific consensus that the climate is changing, and the other argued that the climate is not changing. The research team then analyzed the ensuing discussions. They found that in two of the classrooms, the teachers dominated the discussions, and that most of the student comments were driven by the teachers' questions. In one classroom, the students engaged directly with each other much more often, and the teacher seemed to support this pattern of discussion by asking open-ended questions and by explicitly bringing up earlier student comments.

Although it wasn't framed as 'argumentation', Jakobsson, Mäkitalo, and Säljö (2009) researched a six-week high school unit in which students worked in small groups to discuss and research two conflicting claims regarding climate change. The students largely directed the work, and the researchers videotaped the discussions. The researchers found that the students were able to assist each other in gaining mastery of the content knowledge, though many students continued to struggle with key issues, such as the distinction between global warming and ozone depletion.

An argument over argumentation: Agnotology

Bedford (2010) defined agnotology as "the study of ignorance and its cultural production" (p. 159), and reflected on his experience using agnotology as a teaching tool in an upper division undergraduate course on meteorology. He emphasized that, while some ignorance results from misinformation, some results from deliberate disinformation. Three years later, a series of articles appeared in *Science & Education*, in which two prominent climate skeptics and their colleagues argued that such an approach ignored the complexity of the climate system, and represented a one-sided presentation of the topic. Bedford responded and the climate skeptics offered their rejoinder (Bedford & Cook, 2013; Legates, Soon, & Briggs, 2013; Legates, Soon, Briggs, & Monckton of

Brenchley, 2013). The exchange struck me as overheated, but it served to bring my attention to the original article while highlighting the dangers of directly confronting mis/disinformation.

Inquiry

It is beyond the scope of this dissertation to explore the varied uses of the word 'inquiry'. Instead, in this section I will discuss two very different approaches that different authors described as 'inquiry'.

Ratinen, Viiri, and Lehesvuori (2013) described a four-lesson inquiry-based unit they developed for 20 pre-service teachers. Each class focused one of four different topics: physics, chemistry, biology, and geography. The students engaged in a variety of activities including labs, demonstrations, group work, and discussion. The research compared the students' thinking before and after instruction by analyzing concept maps, and found that while the maps became more elaborate, many misconceptions remained. In their analysis of the classroom discussions, they found that students were less likely to participate in discussions of abstract topics like chemistry and physics, and recommended that teachers present knowledge in ways that are easy to internalize.

Svihla and Linn (2011) worked with three sixth-grade teachers to test a "web-based inquiry science environment". As a result of their testing, they made several refinements in the learning environment, including: 1) refining the visualizations, 2) limiting the number of choices students could make at key junctures, and 3) adding an activity to help students distinguish 'reflection' from 'energy transformation'. Students showed improved learning over the first iteration, and one of the teachers reported that one refinement helped her better understand albedo. Svihla and Linn concluded, "middle school students can learn about complex systems when the curriculum is carefully designed" (p.673).

Public Engagement in Science

Groffman et al. (2010) asked ecologists to engage in a "wholesale reconsideration" of how they communicate with the public (p. 284). They proposed setting aside the Public Understanding of Science (PUS) model in favor of Public Engagement in Science (PES). PES might take many forms, but all involve two-way communication between the public and scientists. Cooper (2011) also called for greater emphasis on PES over PUS. Moreover, given the highly effective media campaign conducted by 'climate change deniers' (see also Oreskes & Conway, 2010), she argued that climate change educators need to address 'media literacy'. The public encounters much more information about climate science in the media than from informal or formal science educators, and lacking skills to critically analyze media messages, they are likely to be swayed by the more prominent voices.

Critical Approaches: Student Action

Birmingham and Calabrese Barton (2014) discussed a 'Green Carnival' they planned with a group of youth. The research focused on six African American girls between the ages of ten and thirteen who took leadership roles in organizing the Green Carnival. The girls voiced pride both in what they had learned and in their accomplishment in organizing the Carnival. They also expressed a nuanced understanding of their own place within the local and scientific communities, and were able to position themselves both as insiders and outsiders within each community. Despite their radical reframing of social relationships, which placed youths in positions of leadership and authority, the authors did not evince the ‘radical prudence’ that I see as a defining feature of postcarbonism, preferring moderately prudent action. For example, “CFLs” (compact florescent lightbulbs) were mentioned thirty times in the article, while the climate was only mentioned six times.

McNeill and Vaughn (2012) studied the impact of a multi-week urban ecology curriculum (“Urban EcoLab curriculum: A high school urban ecology curriculum”, 2014) that aimed to foster “critical science agency”, which they said involves both understanding scientific concepts and acting on that understanding. They found that after the multi-week unit, the students had a significantly better understanding of climate change than they did before the unit, though the students still had not mastered the language associated with climate science. They concluded that the curriculum helped the students take meaningful action towards addressing climate change, such as using compact florescent lightbulbs and carpooling.

Skamp, Boyes, and Stanisstreet (2013) said that students should be empowered to take “proenvironmental action”. Their research surveyed over 1200 secondary students in England and Australia. The data went through significant analysis, using several derived statistics. Based on their interpretation of these derived statistics (including at many points the assumption that correlation implies causation), they offered advice to teachers. Educators should draw students’ attention to three key behaviors, “eating less meat, using more renewables [including nuclear energy], and […] for English students [eating] fertilizer-free food” (p. 208). They advised against lecturing students, and said students should have the opportunity to discuss and decide for themselves the relative value of particular actions.

Critical Approaches: Environmental Justice

I found two studies that sought to address issues of ongoing social injustice within the context of climate change education. Barraza and Bodenhorn (2012) described a collaborative project between two schools in Mexico and Alaska that both serve indigenous youth. In this program, the students engaged in one month of field studies in both Mexico and Alaska (for a total of two months of field experiences). The students worked together on authentic science experiences, to learn about climate change in a way that framed place-based learning in a global context. Unfortunately only 12 students had the opportunity to participate in the experience, and I suspect that cost might prohibit other teachers from using this as model. Chandler's (2009) dissertation documented how three educators used a curriculum on environmental justice and climate change that examined the events in New Orleans surrounding Hurricane Katrina (Crocco & Grolnick, 2008). The lessons focused on watching and discussing Spike Lee's (2006) documentary *When the Levees Broke*.

Postcarbonist approaches to climate change education

McCright et al. (2013) described three interdisciplinary STEM units for use in undergraduate education. Their work was explicitly motivated by the urgent need to improve climate change education and their recognition that climate change transcends traditional disciplinary boundaries. They made the "key assumption" that students' mental models were "simple, linear and static", while climate change involves "complex, nonlinear and dynamic […] phenomena". Moreover, they asserted that developing pedagogical strategies to promote a "shift to systems thinking" including "nonlinearity, stochasticity, feedback loops, and so on" should be "*the* focus of sustained STEM education research [emphasis added]" (p. 714). The lessons all could be adapted to K-12 education, and the authors recognized that the lessons could be improved by partnering with social scientists in continuing refinement.

Hicks (2011) pointed to four fundamental challenges that geography teachers should address in their efforts to build a better world: "i) the nature of human well-being; ii) the impact of climate change, iii) the dilemma of peak oil; and iv) the transition that needs to occur as a result of these" (p. 9). He acknowledged that teachers are already doing "good things" in their schools, and asked them to think about several questions that might inform their teaching practice in the future. These started with a set of questions about what constitutes a good life, and whether continuing economic growth in wealthy countries contributes to human well-being. The article ended by recognizing that the years ahead constitute a "long emergency" and that teachers need to contribute to "education for upheaval" that the current crisis demands.

Sharma (2012) focused on the links between natural and social systems. He argued that given "the perils of climate change for human civilizations" (p. 33), climate change should play a central role in science education. He turned a critical eye on capitalism, saying "global climate change is an outcome of fundamental problems that afflict capitalist societies' relationship with natural systems" (p. 45). He argued that linkages between natural and social systems should be one of three "*core ideas*" not just in earth science but in school science at large (p. 47).

What resources do teachers use in teaching and learning about climate change?

A google search using the phrase "teaching about climate change" yielded over 75 million results. Many government agencies maintain websites with teaching resources (for example Jenkins, Jackson, & Tenenbaum, 2014). Many organizations, including media companies, develop teaching resources and distribute them with little to no field testing (for example Cutraro, 2014; "Nova beta," 2013). Teachers often share resources with colleagues, and many websites facilitate this sharing. A large body of educational research involves developing resources for teachers to use, training teachers in the use of those resources, and then following up with the teachers. Still, I could find no research describing the resources teachers use when they are not themselves involved in a curriculum development project, so this dissertation may fill a void.

Recommended resources

The IPCC *Summaries for Policymakers* (IPCC, 2013c, 2014a, 2014b) could be important resources for teachers to learn about climate change, but readers who are not already grounded in climate science might struggle to make sense of them. One goal of climate change education might be to support learners so they can extract meaningful knowledge from these texts, and one measure of 'climate literacy' might be the ability to read these texts with understanding. Kitchen (2013) wrote an excellent undergraduate textbook that could be a vital at-hand resource, or even a summer read, for any teacher who wants to learn climate science. Smith's excellent (2012) lectures for his undergraduate meteorology course are available for free.

Magazines, like *The Green Teacher*, *Science Scope*, and *The Science Teacher* offer lesson ideas. While these have not been formally field tested, most of the articles are written by experienced teachers, and have been refined by practice. GEMS makes consistently high-quality resources, and they have two units related to climate change (Hocking, Sneider, Erickson, & Golden, 1990; Sneider, Golden, & Gaylin, 2008).

Not a Recommended Resource

The Heartland Institute is a conservative think tank founded in 1984. It worked with the tobacco industry in its efforts to question medical research on the threats of second hand smoke. It is widely seen to be the leading organization advocating 'climate change skepticism'. Many reports suggest that a significant fraction of the Institute's funding comes from the fossil fuel industry (e.g. Revkin, 2009). Holmes (2012) reported that the Heartland Institute is planning to develop a curriculum for use in US schools to question the scientific consensus. This follows their sending 14,000 free copies of *The Skeptic's Handbook* (Nova, 2009) to US public school board chairs.

What institutional factors influence teacher decisions around climate change?

A number of institutional factors may influence teachers' decisions about how and what to teach about climate change. These include standards, guidelines drawn up by national organizations, and exam requirements. Teachers often use their discretion when acting within institutional structures, and this may be especially common in regards to climate change.

Many teachers are heavily influenced by state standards, and almost all are asked to justify their teaching decisions by reference to those standards. Appendix A lists relevant GPS ("GeorgiaStandards.org," 2011), and any public school teacher in Georgia is expected to align his or her curriculum with those standards. Climate change is not explicitly mentioned until high school. Even when climate change is mentioned, it is never given prominence. A teacher who is committed to climate change education would need to look beyond the standards for guidance.

Climate literacy: The essential principles of climate sciences, a guide for individuals and communities (U.S. Global Change Research Program, 2009) was drafted through a process that involved 14 U.S. government agencies and departments of the first Obama Administration as well as 24 scientific and educational partners. It defined climate science literacy as "an understanding of your influence on climate and climate's influence on you and society" (p. 4). Its subsequent discussion of seven key aspects of climate science literacy included a number of topics that would be appropriate to discuss in biology and social studies classes.

The Earth Science Literacy Initiative (2009) worked with nine partners (including the USGS, the Smithsonian Institution, and two national teachers' organizations) to draft *The Earth Science Literacy Principles*. Many of the principles have clear relevance to climate change. They are organized around nine "big ideas", and Big Idea 9 is "Humans significantly impact the Earth" (p. 12). In elaborating on this, it says:

> **Humans cause global climate change through fossil fuel combustion, land-use changes, agricultural practices, and industrial processes.** Consequences of global climate change include melting glaciers and permafrost, rising sea levels, shifting precipitation patterns, increased forest fires, more extreme weather, and the disruption of global ecosystems.

Many topics covered in AP Environmental Science (The College Board, 2013) relate to climate change. 10-15% of the exam questions are devoted to "global change" with "global warming" listed as one of the topics covered under global change (p. 9). A set of sample questions included with the course description suggests that global warming may get special attention. Two of 20 multiple choice questions directly related to global warming, as did 1 of 4 free response questions. Many of the topics covered in AP Biology (The College Board, 2012) offer opportunities to discuss aspects of climate change, but it would be possible to teach AP Biology without mentioning climate change.

Berkman and Plutzer (2010) investigated teacher practices around another controversial topic–evolution. They found that many teachers were influenced by state and national standards and guidelines, but local administrators were often more influential. Many teachers acted autonomously, and sometimes willfully contradicted state standards. In a later work, the authors voiced concern that teachers who want to teach climate change may face pressure not to do so from local administrators, and teachers who question the scientific consensus may contravene state standards on their own authority (Berkman & Plutzer, 2012).

What sociocultural challenges and supports may impact teachers?

Pascopella (2012) pronounced, "climate change is the new evolution debate" (p. 24). Superficially the two are similar. About 45% of the American public avow young earth creationism (Newport, 2012), and about 35% state their belief that climate change either will never happen or will not happen within their lifetimes (Newport, 2010). Internationally, the United States sits near the bottom of nations surveyed on public acceptance of evolution (J. Miller, Scott, & Okamoto, 2006), and it is near the bottom of how seriously the public takes the threat of climate change (The Pew Research Center for the People and the Press: Global Attitudes Project, 2009). Both global warming and evolution are considered fronts within the larger culture war (Hoffman, 2012). Most importantly for teachers, as with evolution, the issue of climate change stirs strong emotions, especially among those who distrust the science (Lombardi, 2013).

These similarities mask important differences. While the level of evolution acceptance has been virtually unchanged for decades, opinions on climate change are in flux. The Yale Project on Climate Change Communication (Leiserowitz et al., 2014) found that in just one year, the number of respondents who stated that they believe global warming is human-caused dropped by about 7% (from 54% to 47%). The direction of this shift might cause concern, but education could have a real impact: About 3 in 10 respondents said they "could easily change their mind about global warming" (p. 20); only 4 in 10 respondents knew that most scientists think global warming is happening; and less than 1 in 4 knew that scientists are in consensus that humans are largely responsible (p. 11-12). So simply informing people of the consensus in a convincing manner could dramatically shift public acceptance of the reality of climate change.

Religion plays a very different role in the climate change and evolution debates. Kvaløy, Finseraas, and Listhaug (2012) surveyed over 67,000 individuals in 47 nations to investigate the factors that impact concern about global warming. The researchers developed a regression model that included 18 variables. Religious identity was not included in the model, but people who take time for "prayer, meditation or contemplation" expressed greater concern for global warming than those who did not, and this was the fourth largest-magnitude regression coefficient. The three variables with the largest-magnitude regression coefficients[16] all involved political ideology (p. 18).

[16] I am not considering the intercept as a coefficient.

Postcarbonist framings of the sociocultural debate

McCright (2011) adopted the language of statistics to argue that political orientation "moderates" measured associations between several demographic variables (including educational attainment, race, gender, and party affiliation) and concern about climate change. He drew on reflexive modernization theory to argue that the social and political debate over climate change is symptomatic of a larger societal shift.

> This reflexive modernity is characterized, above all, by the increasing salience of low probability, high consequence risks that are no longer circumscribed spatially or temporally (e.g., genetic engineering and nuclear technologies). Indeed, climate change—the most expansive unintended consequence of industrial capitalism—is the quintessential risk of this era. Other key characteristics of reflexive modernity are heightened systems complexity, the pervasiveness of uncertainty, and enduring pressures on institutions to protect their legitimacy in the face of crises and challenges. (p. 245)

He argued, "critical self-confrontation […] is a necessary precondition for effectively dealing with this new round of ecological and technological crises". During periods of social transformation, forces mobilize to defend the old order. Given the role of science in understanding climate change, the reactionary forces foment doubt about the science. But the underlying conflict is not about science: It is about industrial capitalism. "Climate change poses such a fundamental challenge to the industrial capitalist order, dealing with this global environmental problem (and even acknowledging its reality) heightens the clash between opposing forces of reflexivity and anti-reflexivity" (p. 245).

In *Why we Disagree about Climate Change,* Hulme (2009) offered a frame that combines my understandings of postcarbonism and postmodernism. He argued that–while there may be some disagreement about the science–fundamentally, we disagree about climate change because of deeper cultural differences. Climate change has accreted to itself a range of global problems, including poverty, biodiversity loss, and "hyper-consumption". Even if the climate stabilizes within the next one hundred years, these problems will not be solved, nor will our underlying differences disappear.

These differences give rise to varied narratives and a resulting logjam. Hulme faults in the IPCC and the UNFCCC for framing climate change "as a mega-problem awaiting, demanding a mega-solution" (p. 333). He sees climate change is a "wicked problem" that awaits "clumsy solutions" that simultaneously pursue several contradictory goals and will not achieve any of them. He concluded that religions are generally more concerned with confronting problems than with solving them, and proposed a set of four "myths" that may allow humans to look at ourselves in the mirror, and see "the contradictions and limitations that make us human" (p. 360).

Fossil fuel consumption is deeply embedded in every element of modern American life, and 'climate' has deeper social meanings than the statistical definition I offered in chapter one. Given these complexities, science educators would be mistaken to think of climate change as the "new evolution debate". It is not just a problem for biblical literalists. It's a problem for everyone, and the problem is likely to grow ever more wicked over the next one hundred years.

CHAPTER 3

METHODOLOGY

This study explores current teacher practices around climate change education in Georgia. In particular, it aims to answer five research questions.

RQ1: What do teachers teach about climate change?

RQ2: How do teachers teach about climate change?

RQ3: What resources do teachers use in teaching and learning about climate change?

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

The first two questions directly address the 'what' and 'how' of teacher practice. The last three questions touch on some of the 'why's of teacher practice by looking into three factors that may influence teachers' thinking about climate change education. Yin (2009, p. 8) reviewed the methodologies available to social science researchers, and concluded that any approach can answer 'what' questions, but that case studies are especially useful for answering 'how' and 'why' questions about contemporary events over which the researcher has no control. Accordingly, I adopted a case study methodology.

This case study explores K-12 climate change education in the Atlanta metropolitan area (Metro Atlanta) during Fall 2013. Stake (1995, pp. 3-4) distinguished three kinds of case studies–intrinsic, instrumental, and collective. Intrinsic and instrumental case studies are distinguished by whether the case is intrinsically interesting or it helps you understand something broader. I studied the case to understand climate change education in Georgia, so this is an instrumental case study.

I studied more than one instance of climate change education, making this a collective case study. Just as a system includes subsystems, this case study includes subcases. The five subcases interacted in numerous ways. Three of the teachers in this study were teaching about climate change at the exact same time, and two of these were teaching in the same building. Another pair of teachers are also colleagues, and two teachers know each other through their involvement in organized Earth science education. Moreover, my involvement in each of subcases wove them into a single case. One time, I casually mentioned to one teacher (Annette) how another teacher (David) talked about a difficult concept, and the next day, David's words came out of Annette's mouth. All of the teachers expressed curiosity about the other teachers' practice, and all wanted to hear my thoughts on how to improve their individual practice. The subcases are also united in my analysis. I asked the same questions of each case, and I am making one key assertion in all five cases. This dissertation is titled, 'A collective case study of climate change education in Georgia'; in fact it is 'A collective case study of climate change education in the Atlanta metropolitan area during the Fall of 2013'; in truth, it is 'What Len Bloch saw and came to believe while writing his dissertation'.

The Setting

Yin (2009) noted that in many ways, case studies are like history (p. 11). I have already discussed this study's larger historical context as the Earth enters the

Anthropocene. I also suggested that this study may have historical value as a record of teacher practice just prior to the promulgation of the NGSS. But historical context encompasses more than science standards and changes in the Earth system.

The Time: Fall 2013

In Fall 2013, the IPCC released its report on the physical science of climate change (IPCC, 2013c), and the US government had a partial shutdown, which would hinder the work of climate scientists for months afterwards (Mervis, 2014). Typhoon Haiyan, the strongest storm even to make landfall in history, devastated parts of the Philippines.[17] As 6000 Filipinos were dying, in Warsaw, the 19th Conference of Parties (COP 19) achieved little beyond a commitment by the member states to continue talking (United Nations Climate Change Secretariat, 2013). The COP's most memorable event was the tearful speech given by the Philippines' delegate to the conference, Yeb Sano. Two minutes and 8 seconds into one recording of the speech (The Daily Conversation, 2013), he announced:

> In solidarity with my countrymen who are struggling to find food back home and with my brother who has not had food for the last three days, […] I will now commence a voluntary fasting for the climate, this means I will voluntarily refrain from eating food during this COP, until a meaningful outcome is in sight.

[17] I do not mean to imply that Typoon Haiyan resulted from climate change. The IPCC (2013b) noted, "Current data sets indicate no significant observed trends in global tropical cyclone frequency over the past century […]" (p. 216), and "Confidence remains low for long-term (centennial) changes in tropical cyclone activity […]" (p. 162). Tropical cyclones seem to be getting stronger and more frequent in the North Atlantic (p. 162), so climate change may be relevant to Katrina and Sandy. But no such claim can be made for the Southwest Pacific.

Sano's heartfelt action inspired uncounted followers, and a movement to fast for the climate continues to this day.

The Place: Atlanta Metropolitan Area (Metro Atlanta)

Atlanta is Georgia's capital city, and the Atlanta metropolitan area (Metro Atlanta) spreads over 8000 square miles, encompassing more than half of Georgia's population.[18] Metro Atlanta is home to over 5 million people, but less than ½ million of them live in the city of Atlanta. Throughout the 20th century, most of the area's population was European American (white), with African Americans (blacks) making up most of the remainder. But the demographic climate is changing. Between 2000 and 2010, Metro Atlanta's population grew by over 25%; the Hispanic population doubled, and the Asian population almost doubled. Metro Atlanta is growing in size and diversity, and within the decade, whites will probably lose their majority status.

The demographic groups are divided. Although Georgia is racially diverse, only 2% of its people are identified by the census as "mixed race". Metro Atlanta's diverse communities are divided geographically. Many of the suburbs (including the one suburban school I observed) are predominantly white, while the city of Atlanta (like the more urban schools I observed) is predominantly black with large populations of whites, Hispanics, and Asians. The demographic differences echo political differences. The suburban white district I visited served a community that cast a majority of its votes for Mitt Romney in the 2012 presidential election, while the more urban schools in this study served counties that voted overwhelmingly for Barack Obama in the same election.[19]

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[18] Much of what follows is based on information from http://quickfacts.census.gov/qfd/states/13000.html.
[19] http://uselectionatlas.org/RESULTS/index.html

Metro Atlanta's meteorological climate is also changing (see Figure 10). The area experiences frequent heat waves, and its sprawling Urban Heat Island exacerbates the heat (Zhou & Shepherd, 2010). On average, heat waves cause greater mortality than any other natural hazard, and heat waves in Metro Atlanta can no longer be considered purely a natural hazard. Yang and Lo (2003) estimated that unless measures are taken to limit growth, 51 ha/day will be converted to urban use between now and 2050, and even with such measures 32 ha/day are likely to be converted to urban use. Without very aggressive mitigation efforts, Metro Atlanta's physical climate is likely to worsen over coming decades. Global climate change is likely to aggravate the problem, but Metro Atlanta's population is already feeling the effects of local and regional climate change.

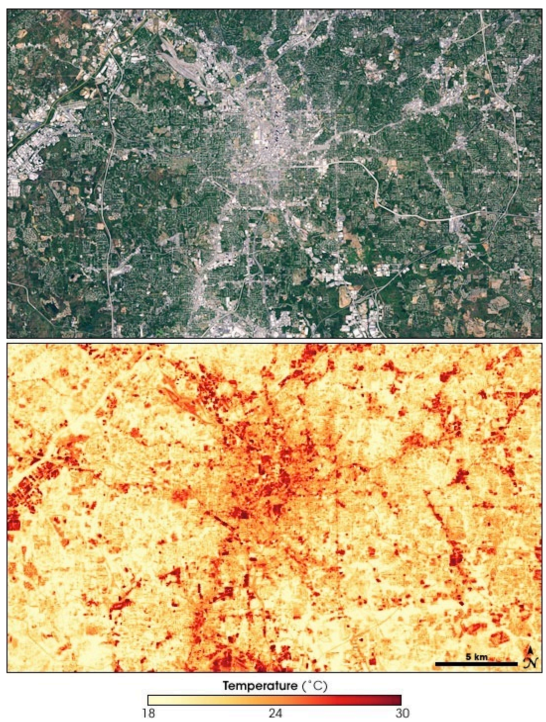


FIGURE 10
Metro Atlanta's urban heat archipelago as recorded on September 28, 2000. Top image shows Atlanta and some of its suburbs in true color. Bottom image is a land surface temperature map based on infrared imaging. [20]

[20] Public domain image by Marit Jentoft-Nilsen; reprinted in Przyborski, 2008.

A Postcarbonist Case Study

> A paradigm is a worldview […]. Paradigms are also normative, telling the practitioner what to do without the necessity of long existential or epistemological consideration. But it is this aspect of paradigms that constitutes both their strength and their weakness–their strength in that it makes action possible, their weakness in that the very reason for action is hidden in the unquestioned assumptions of the paradigm. (Patton, 2008, p. 423)

As far as I know, no case studies have been written using a postcarbonist framework, meaning that there are no paradigmatic works to serve as models for this work. While I want to avoid "long existential or epistemological consideration", I owe it to readers to describe how my postcarbonist stance influenced my methodology. In Chapter One, I identified four aspects of my understanding of postcarbonism: 1) a focus on adaptive mitigation, 2) transdisciplinary research, 3) a critique of capitalism, and 4) a focus on systems and systems dynamics. In this section, I will discuss each of these in turn, though I will focus on the later two.

Focus on Adaptive Mitigation and Transdisciplinary Research

The focus on adaptive mitigation underlay my decision to look at K-12 education. Today's youth will need to adapt to life on a changing planet while mitigating greater future harm. Understanding how teachers prepare children for an uncertain future informs our thinking on how we might encourage greater adaptiveness in those same youth. My focus on adaptive mitigation will also impact my analysis and my recommendations for further research.

My thinking on climate change education is deeply transdisciplinary. The previous section discussed the relationship between demographic shifts, suburban sprawl, the *de facto* segregation of Metro Atlanta's schools, and changes in the meteorological climate. This was not born of a conscious attempt at a transdisciplinary unification of Metro Atlanta's physical, social, and meteorological climates into a single dynamic system. It simply reflected how I think. Rather than striving to be transdisciplinary, in this dissertation, I am making a conscious effort to limit my discussion of the natural sciences to a level that might be tolerated by readers who expect a dissertation in science education to model itself on existing paradigms of social science research.

Critical Theory

Critical theory allows researchers to advocate for change, to question the ideology of the society they live in, to work with participants in the joint production of knowledge, and to take action to improve the world. So while I am more interested in the question of human survival than human liberation or justice, I have conducted my research from a critical framework. I am: 1) advocating for more and better education about climate change, 2) questioning the ideology of my society (capitalism), and 3) working with teachers in the joint production of knowledge while taking action to improve the world. Most importantly, critical theory *demands* that researchers take a stand.

Bias

Given my clear stand on one-side of a divisive social and political issue, I am prepared to face inevitable charges of bias. It is not enough to state my biases up front, I must "take special care to construct and conduct research that is rigorous, trustworthy, and authentic" (Shields, 2012, p. 3). I must also be sensitive to my susceptibility to conformational bias, which Nickerson (1998) defined as the *unwitting* tendency to seek information that confirms existing beliefs while dismissing disconfirming evidence. Kahan and colleagues have found that confirmation bias affects people's thinking about controversial science topics (2011), and that the more informed people are about climate change, the more prone they are to biased assessments of the risks associated with climate change (2012). Accordingly, whenever I perceive the threat of conformational bias, I will question my own bias, and will actively consider the possibility that I may be wrong.

Follow-up

Shields (2012) wrote, "an essential component of critical […] research is for the researcher to engage the stakeholders on an ongoing basis with the findings and implications of a critical research study" (p. 9). The teacher-participants are obvious stakeholders, and I have communicated with them throughout the research process. I have shared my analysis with each of them, and plan to continue to do so. Other stakeholders include school and district administrators as well as science education researchers, curriculum developers and advocacy organizations.

The Evolving Systems Approach

In *Creative people at work: Twelve cognitive case studies*, Gruber (1989a, 1989b) proposed an "evolving systems approach" to case study research, and suggested that such an approach "may also provide a valuable springboard for useful reflections of the greatest moral question of our age–how to work effectively for the survival of our species" (1989a, p. 278). At first glance, the phrase "evolving systems" echoes postcarbonism's focus on dynamic systems, and Gruber's concern for "survival" echoes postcarbonism's similar concern. While Gruber's approach puts aside the formal modeling used within systems dynamics, it may offer a tool for understanding the lives and actions of individual humans through a systems lens.

Gruber's described his approach by referring to several "attitudes" that case study researchers can adopt. The approach is:

1) *Developmental and systematic*: All of the teachers in this study have been practicing their craft for over ten years. In our discussions, they often reflected on how their teaching has evolved over the years. My analysis also looked at the "interplay of purpose, chance, and insight" (p.4) in each of the subcases, and the collective case is understood to result from such an interplay in my own creative process as well as the interplay between the subcases.

2) *Pluralistic*: The teachers in this study drew on a variety of resources in practicing their craft. The collective case will encompass the plurality of teachers in the study.

3) *Interactive*: Each of the teachers in this study "works within some historical, social, and institutional framework" (p.4). Each in turn influences his or her environment, and as teachers, they were all aware of how they impacted their students. As a collective, they were all interacting with me, and often with each other.

4) *Constructionist*: All of the teachers in this study took an active role in "shaping the environment in which the work proceeds" (p. 5). (In most, but not all cases, they arranged the desks and decorated the room in which the teaching took place.) While participating in this study, they all reflected on their own teaching practice and often talked about how they might change their practice in the future. In other words, they

actively engaged in the work of reconstructing their practice during our discussions, and often involved me in that work. The collective case will be constructed out of my understanding of the individual cases.

5) *Experientially sensitive*: The teachers are "not considered simply as the doer[s] of the work, but also as [people] in the world" (p. 5). All were aware "of the relation of [their] work to the world's work" (p. 5), and the collective case study is shaped by a similar awareness on my part.

Limitations to the Evolving Systems approach

Most of the cases in Gruber's book encompassed entire creative careers, but I observed brief episodes. I could discern subtle changes in teacher practice during my observations, but I have primarily relied on the teachers' descriptions of how their practice has changed in analyzing their practice as an evolving system. Moreover, Gruber defined his evolving systems approach by reference to several attitudes, and offered very little guidance on how to actually conduct case study research using the approach. I will now turn to that question.

Selection of Research Participants

Georgia's science standards do not emphasize climate change, so teachers who teach about climate change in depth are *prima facia* non-representative, and this is not a random sample. I purposefully searched for interesting, and potentially exemplary, cases (Simons, 2009, p. 34). The five participants in this study met several criteria:

1. They were employed as K-12 teachers during the 2013-2014 school year.
2. They planned to spend at least forty-five minutes teaching about climate change while working with a single group of students.

3. The collectivity included at least one elementary school, one middle school, and one high school teacher.

4. Each teacher had insights based on prior experience teaching about climate change.

I recruited the teacher-participants by network and snowball sampling (Patton, 2002). I started by asking professors and fellow graduate students to recommend people who might participate in the study. This yielded one participant (Tom Butler). I also expanded my personal network by participating in two teacher workshops on climate change. I met two participants at one of these workshops (Annette Brown and Jeff Zale). A participant in the other workshop put me in contact with David Woolf, who in turn introduced me to his colleague, Grace Chapman.

I was largely successful in finding exemplary teachers. All of the teachers have at least ten years of experience. Two have earned Ph.D.s. One is the former Teacher-of-the-Year in his school. Another was once Teacher-of-the-Year in his district and was recognized as the outstanding Earth Science Educator in the Southeast region, and he has twice gone to Greenland to participate in climate change research. Even those teachers who lack such exemplary credentials struck me as excellent teachers.

The teachers interacted with me, and often with each other, as the collective case study unfolded, so I will discuss the cases in chronological order based on my first class observation with each teacher. Keep in mind that the first three teachers were all teaching about climate change at the same time, and over a two-week period, I was jumping from one classroom to another. Table 1 provides a brief summary of the participants.

TABLE 1

Research Participants

Pseudonym	School Environment	Level Taught	Years of experience/ in current position	Notes
David Woolf	Urban Science Center	High School	18/14	* Ph.D. in Geology * Co-authored mass market book on Georgia's geology * Helped write GPS on Earth Systems Science
Jeff Zale	Large Suburban School	High School	25/23	* Ph.D. in Science Education * Department Chair * Former Teacher-of-the-Year
Annette Brown	Large Suburban School	High School	15/9	Works with Jeff Zale
Tom Butler	Midsized Urban School	Middle School	13/13	* Outstanding Earth Science Teacher for the Southeast Region * Former District Teacher-of-the-Year * Participated in climate change research in Greenland
Grace Chapman	Urban Science Center	Elementary School	13/13	* Mainly teaches subjects related to human anatomy and physiology * Works with David Woolf

Data Collection

I gathered and generated four types of data: direct observations, interviews with the teachers, artifacts of instruction, and related media including teacher resources and policy documents. Appendix B contains the interview and observation protocols, an overview of other data sources, as well as the consent form signed by each participant.

Direct and Videotaped Observations

My analysis centered on direct and videotaped observations of classroom practice. Whenever possible, I observed each class personally. Unfortunately, the three high school teachers were all covering climate change at the same point in the fall semester, and this forced me to prioritize some observations over others. I was able to observe all of David Woolf's lessons on climate change, and Jeff and Annette both accommodated me by recording portions of their classes when I wasn't present. During the direct observations, I took handwritten field notes. Much of the analysis relied on the videotapes, and I transcribed about half of what each teacher said during his or her direct classroom instruction.

Interviews

The interview protocol called for three audio-recorded 60-minute semi-structured interviews with each of the participants. The first interview was to be conducted prior to the observations, the second midway through the observations, and the last at the end of the observations. I followed this protocol with four of the five participants, but I only interviewed Grace twice. Her climate change unit consisted of a single class, and the protocols for the second and third interviews would have covered a lot of the same material, in that the second discussed a single class, while the third reviewed the entire unit. I decided not to make undue demands on her time.

The interview protocols were designed to inform each of the research questions. The first interview provided information on how the teachers taught, while inquiring into: 1) the sociocultural environment at the school, 2) the teachers' goals for their climate change instruction, and 3) how they personally learned about climate change. The second interview focused on a single class and the resources that were used in preparing the class. The third interview asked the teachers to reflect on: 1) their entire climate change unit, 2) their sociocultural and institutional supports in teaching about climate change, and 3) how the University of Georgia might better support them. The interviews were transcribed and the analysis used both the transcripts and the audio recordings.

Artifacts of Instruction

I collected and analyzed artifacts of instruction, including handouts, powerpoints, photographs of lab setups, quizzes, textbook chapters, project descriptions, etc. All the high school teachers provided large collections of computer files that included artifacts of previous years' instruction. Occasionally, I would use the artifacts of instruction to make inferences as to what resources the teachers used in preparing their lessons. The web-based reverse image search tool Tineye.com proved especially useful: Often I could copy an image from a powerpoint into Tineye, and quickly discover what websites the teachers used in preparing their lessons.

Related Media

Often the teachers would tell me what resources they used in preparing their lessons or what policy documents informed their instructional approaches. These resources and documents were often available online. Usually, I could find copies of textbooks in the library, and I xeroxed one chapter of a teacher's textbook.

Data Analysis

> Qualitative data analysis transforms data into findings. No formula exists for that transformation. Guidance, yes. But no recipe. Direction can and will be offered, but the final destination remains unique for each inquirer, known only when–and if–arrived at. (Patton, 2002, p. 432)

This dissertation focuses on the practical art of teaching. My data analysis therefore relied most heavily on the classroom observations, and I focused the greatest attention on the first two research questions, which concerned the 'what' and 'how' of the teachers' practice. The other questions–what resources the teachers used, and how they reflected on the sociocultural and institutional environment in which they teach–are important to the degree that they helped me understand their teaching practice. Therefore in analyzing the results, I focused on describing what happened in each individual classroom, and addressed the other three questions in reflecting on classroom practice.

Writing as Interpretation

Simons (2009) advocated "writing as interpretation". She explained "writing and rewriting is an integral part of coming to an interpretation of a case", and noted that in some cases, it is "the key interpretative process" (p. 142). I've learned that I often don't know what I think about a subject until I try to write my thoughts. Accordingly, I analyzed the cases by writing about them.

Each of the case reports starts with a set of assertions (Stake, 1995, p. 9). The assertions represent the core of my interpretation. But for me interpreting the data involved writing about it, and the assertions can also be viewed as the distillation of my writing process. I placed them up front to assist the reader.

Work Flow

My data-analysis/writing process evolved as I gained experience. By the time I had written up two cases, I developed a work-flow (see Table 2) that consistently allowed me to integrate all of the data sources and my analysis into a single case report.

TABLE 2

Work Flow

Task	Data Source	Notes
Conduct and transcribe interviews	Audio recording	I transcribed 6 of the interviews; a transcriber did the other 8.
Observe and videotape classes	Direct observation	I kept my handwritten field notes in bound notebooks.
Listen to interviews and write preliminary memos and musings.	Audiorecording and interview transcripts.	I listened to each interview at least twice.
Watch videotapes and write elaborated field notes.	Videotapes of classroom teaching. Artifacts of instruction.	The elaborated field notes were often quite long, and served as a zeroeth draft for the case report.
Preliminary coding	Printed Interview transcripts	I wrote preliminary codes and short memos by hand.
Elaborated coding.	Electronic Interview transcripts.	I entered by preliminary codes onto Dedoose's online qualitative research service and added new codes as I reread the transcripts.
Rough draft	Elaborated field notes. Coded interview transcripts. Artifacts of instruction. Other media.	The rough draft was assembled out of the various writings I had assembled.
Near final draft	Rough Draft.	The rough draft typically needed to be shortened by about 50%.
Advisor checking.	Revised draft.	With the first two case reports, there was a large amount of back and forth with my advisor before the drafts were ready for member checking. In the later case reports, this step was almost perfunctory.
Member checking.	Near final draft.	Each teacher read the near final draft and offered his or her input.
Final draft.	Near Final Draft. Member checking email.	The teachers' input always focused on discrete aspects of the analysis, so the revisions were quite small.

Analyzing the Interviews

I used memos, musings, and codes to analyze the interviews. Memos were obviously connected to the data and often shorter than musings, while musings sometimes went very far from the data, and reflected the quirkiness of my thought process. I also coded the interview data. Rather than using codes within the grounded theory methodology, I used them to aid my interpretive writing. I went through two rounds of coding. Preliminary coding was done on print outs of the interview transcripts. I would read through the interviews using a mix of open and focused codes. The focused codes included five codes (RQ1, RQ2, etc.) corresponding to my five research questions. I often attached multiple codes to a single text: Many texts were assigned multiple 'RQ' codes, and almost all of the 'RQ' codes were elaborated with other codes. Then I would upload the transcript to the online qualitative analysis service, Dedoose, and enter my initial codes as I reread the transcript and added more codes. Although the words I use to describe my coding process, including 'open' and 'focused' codes are borrowed from grounded theory (Charmaz, 2006), I used the codes as a tool to deal with the large amount of data that I was analyzing in writing my interpretation. The ability to quickly find excerpts of text that I could use in writing up my case reports aided my writing process, but I make no claims that the codes emerged from the data, or that themes emerged from the codes.

Field Notes

I wrote my field notes in two steps. The first were handwritten field notes made during the direct observations. I used composition books, and recorded what I was observing on the right-hand page, while noting any thoughts or questions I had on the left side. I referred to these in writing the elaborated field notes while watching the videotapes of the classes.

The elaborated field notes were often quite long, and included transcripts of about half of each teacher's direct instruction to the class. When the teachers weren't engaged in direct instruction, I often followed them around the room, while recording their conversations using my cell phone. I did not listen to all of these recordings in developing my elaborated field notes, but I noted particularly interesting recordings in my written field notes, and I listened to many of these. The elaborated field notes served as the zeroeth draft of each case report.

Researcher Subjectivities

Stake (1995) said that qualitative research aims to promote a subjective research paradigm. "Subjectivity is not seen as a failing needing to be eliminated but as an essential element of understanding" (p. 45). My subjectivities framed the assertions I made, and your subjectivities as a reader will impact your understanding of those assertions. Within a subjective research project, the problems inherent in subjectivity cannot be eliminated and must be addressed head on. Accordingly, I will speak to three aspects of my subjectivity that impact this study. I am a teacher, a science fan, and a fool.

Teacher

I struggle with the word 'educator'. It is derived from Latin: 'Ducere' means 'to lead' and also gives us the noble title of 'Duke'; the prefix 'e-' is short for 'ex-' meaning 'out', as in 'exit'. To 'educate' means to 'lead out'. Perhaps the word asks us to imagine that our students are trapped in Plato's cave and that our job as educators is to lead them out of darkness. ‘Teach’ comes to us from the Old English ‘tæcan’, meaning ‘to show, to point out’. It is distantly related to the word ‘touch’. Perhaps our job as teachers is to point to the light, and hope that our students may lead us out of darkness. Perhaps our job is simply to touch our students. Either way, I aspire to be a teacher.

I like the sounds of school–the shrieks and laughs in the lunchroom, the murmur of a working classroom, the quiet of empty halls after the day's lessons are done. Mostly, I like children, and I like helping them learn. I like teachers, and I like teaching.

Science Fan

I love science. If given the choice between trudging though one article in *The Journal of Research into Science Teaching*, or flipping though ten issues of *Science* or *Nature*, while pondering the problems, musing over the methods, considering the conclusions, and reviewing the references… well, frankly there's no choice. In fact, I have spent many a lazy afternoon doing exactly that.

A part of me is thrilled to have the opportunity to witness what seems to be a state shift in the Earth System. I’m curious to learn if the same principles that apply to small ecosystems, like lakes and ponds, apply to the whole Earth. A part of me wishes I could live for a thousand years, just to see how this plays out.

But only a fool could imagine that he could live for one thousand years–or desire such prolonged suffering.

Fool

> […] even if God in heaven and all the angels offered to help him out of [his torment]–no, he does not want that, now it is too late. (Kierkegaard, 1849/1980, p. 72)

During my forties, I suffered two setbacks that pushed me to the edge of despair. First I went through a painful divorce. While I was dealing with its aftermath, my head got whipped around in a car accident, and I suffered an injury that silenced my voice for a year and a half. It seemed my teaching career was over. So while I still enjoyed the love of family and friends, I found myself teetering on the edge of despair when I arrived in Georgia. I have since come to believe that all human beings live on the edge of despair, and that fact may give life its meaning and purpose.

Becker (1973, 1975) argued that humans crave eternal life, even as we live with the certain knowledge of our own mortality. The inevitability of death produces a profound existential dilemma, which has the potential to create a paralyzing anxiety for anyone who seriously considers the implications of his or her complete annihilation. According to Becker, humans escape the dilemma through involvement in an "immortality project", in which individuals either create or participate in a symbolic undertaking which–given its purely ideal nature–has the potential to continue forever.

After reading some of the medical literature on end-of-life care (see Chochinov, 2005; Chochinov & Cann, 2005; Chochinov et al., 2011), I replaced Becker's "immortality project" in my own mind with 'transcendental need for meaning and purpose'. While Becker's language highlights to the futility of our strivings, I am convinced that–while human efforts to find meaning and purpose in life may be easily frustrated–they are not as delusional as our attempts to create an "immortality project". Still the two conceptions are not entirely distinct, and Becker would no doubt consider my reluctance to accept his language as a form of denial.

Varki and his colleagues (Varki, 2009; Varki & Brower, 2013; Varki et al., 2008) argued that the denial of death (which Varki frames within the larger construct of the human capacity for self-deception) sits at the nexus of the most important moment in human evolution, namely the sudden emergence of modern human behavior between 50-70,000 years ago. Varki and colleagues argued that the ability to deny reality only offers a selective advantage when coupled with another uniquely human trait (which they called a “complete theory of mind”). So self-deception may be very rare in intelligent life forms, and probably does not exist in cetaceans, giant squid, or elephants.

If modern human behavior is rooted in self-deception, then humans may have evolved a unique solution to the existential problem of life. It seems possible that life is devoid of meaning and purpose, that we are little more than worms with large brains. One solution to this problem is to find meaning and purpose in the life of a worm; this is the solution offered by the ecojustice framework. Another solution is to find meaning and purpose in solidarity with the meek and poor; this is the solution offered by the environmental justice framework. Another solution is to find meaning and purpose in the very striving after meaning and purpose. This is my preferred solution, but it comes with a heavy price.

If humanity disappears from the universe, then the only source of meaning and purpose in the universe may also disappear. The task of postcarbonism is not simply to preserve human life; it aims to impact the political, social, and physical climate to allow human beings to live lives rich in meaning and purpose. For me, it is personal. I am confronting a mass extinction, I am confronting my own death, I am confronting despair, and seeking meaning and purpose in that confrontation. I am seeking after wisdom, and engaging in absurd folly.

Limitations

Given the highly subjective nature of qualitative research, this study's greatest limitation is that a fool wrote it.

The research focuses on three sites, and five teachers. It is almost impossible to know if any of the study's assertions may generalize to other settings and teachers. I purposefully selected participants who taught about climate change, sometimes when the relevant GPS didn't mention it. The teachers in this study all agreed to participate, and were all eager to hear my thoughts. There is no reason to believe that they are typical of K-12 science teachers in Georgia.

The study is also limited in time, Simons (2009) wrote:

> Often the meanings of an observation is not contemporaneous. It is embedded in events, stories, incidents that preceded the particular observed event. Frequently we cannot tell the exact meaning without knowledge of the context and history before our arrival on the scene. (p.58)

Often I could conjecture about the teachers' normal teaching style, but these conjectures may or may not be valid. If some teachers presented climate change as uncertain science, did this represent a shift in their teaching styles, or did they also discuss uncertainties in the theory of gravity or the cell theory? With limited context, it is hard for me to understand the meaning of much of what happened in the classes I observed.

Time constraints also limited the depth of my data collection and analysis. I didn't want to place undue burdens on the teachers, so I was careful to keep interviews under an hour. This prevented me from following up on many interesting comments. The inability to be in two places at the same time prevented me from observing three classes that I would have wanted to observe. Finally, my personal desire to finish within a year limited the depth of my analysis, and made the dissertation too long by 50%.

The qualitative methodology coupled with IRB restrictions is also problematic. While my transcripts and field notes could be made available to other researchers, the raw data will be destroyed upon completion of the research. Moreover, the requirement that I maintain confidentiality for the teacher participants means that no one can check with them.

Overcoming limitations

I have attempted to overcome these shortcomings by using many data sources and multiple pieces of evidence to support each assertion. I have attempted to frame this study within a particular place and time, so readers can understand the context. I have tried to be clear about my own biases, in the hope that readers will consider these in making their own judgments. I have been explicit that I am making assertions, and make no claims that I found anything in the data, or that any themes spontaneously emerged from the data.

Consequential Validity

Stake (1995) wrote, "[T]he consequences of [research and methodology] should be considered part of the researcher's responsibility" (p. 108). In designing and conducting this research, I have always considered the consequences for: 1) the participants, 2) their students, 3) myself, 4) the readers, 5) the cooperating districts, 6) the educational community at large, 7) the citizens of the state of Georgia, 8) humanity, 9) the species with whom we share this planet, and 10) a curly-haired girl, who I imagine has children of her own by now.

Considering the consequences for my participants and their students provided the greatest challenge. As a science fan, I often noticed scientific misstatements. I wanted to support the teachers and their students by helping the teachers learn the material they are expected to teach, yet I know that sometimes people don't appreciate being corrected. I therefore used the same approach I have used for decades when grading student papers. I have mixed a lot of sugar with medicine, and I have kept the doses of medicine as low as possible. This is not to say that I flattered the teachers in order to protect their feelings, or that readers have cause to question my assertion that they are all exemplary teachers. I have immense respect for each of them, and learned a great deal from them.

Considering the consequences for myself and my readers has proved a challenge. I have undermined my health while writing this. I know it is too long to reasonably ask another person to read. Had I committed the time to making it shorter, I would have done greater harm to myself. I apologize.

CHAPTER 4

RESULTS

This chapter presents the five reports for each subcase within the collective case study. Each subcase starts with short introduction centered on a set of assertions, and one assertion recurs in every case: "[The teacher's] most valuable resources are [his or her] own skill, knowledge, and personality". Each report then details the teacher's instructional practice and my thoughts on that practice. At the end, I discuss issues that didn't naturally fit into the descriptions of the teaching, and each report concludes with a case summary.

Many of the sections start with short epigraphs taken directly from the data. These are largely an affectation on my part, but I hope that they will help keep the readers' interest.

Case One: Dr. David Woolf – The Importance of Content Knowledge

"Imagine having people who are basically university level academic people in K-12 classrooms every day."

David Woolf doesn't work in a typical school, but at his district's science center. Some of his students come to the science center, where he teaches (among other things) an intensive one-week geology course for ninth graders. He also visits schools as a guest lecturer, and performs a number of other duties for the district. My study of David's case prompts me to make assertions relevant to each of the research questions.

Research Question One (RQ1): What do teachers teach about climate change?

a) David's lessons treated climate change as one aspect of Earth Systems science.

b) He presented climate change as one of many challenges linked to the use of fossil fuels.

c) He presented climate change as a global, national, and local challenge.

d) He presented climate change as a future challenge that needed to be addressed in the present.

RQ2: How do teachers teach about climate change?

a) He framed his lessons around questions, and offered answers to those questions over the course of the lessons.

b) He made heavy use of lecture and powerpoint, and mixed in other short activities.

c) He challenged students to use basic math skills to analyze the climate system.

d) His lessons explicitly discussed political and economic issues related to climate change; at points, he touched on moral issues related to climate change.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) His most valuable resources are his own skill, knowledge, and personality.

b) His extensive knowledge of geology allowed him to make use of a broader range of resources than many other teachers.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) He works in a unique environment that affords him great freedom but brings its own challenges.

b) He has been involved in drafting district and state standards, and does not feel constrained by the standards.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) He didn't discuss the political and social controversy in class, but his thinking on the controversy framed his instruction.

b) He voiced great respect for his colleagues, but voiced frustration that they don't share his sense of the importance of Earth systems science for their students.

c) In his position at the district science center, he has come in contact with many teachers, and had a lot of ideas about how they could be well supported.

Synopsis

David's science content knowledge is unusually strong for a K-12 teacher. In addition to holding a Ph.D. in Geology, for 4 years he worked as a geologist and taught at the university level, before pursing a career in K-12 education 14 years ago. Since becoming a teacher, he co-authored a mass-market book on Georgia's geology, and helped write the Georgia Performance Standards (GPS) for high school Earth systems science. He enjoys his job at the science center, and embraces its staff and mission, saying, "Imagine having people who are basically university level academic people in K-12 classrooms every day". He said this "opens up a two-way street". The academics bring their knowledge to the classroom, and they learn to tailor that knowledge "to the teacher's needs because the academic learns about those needs and the classroom environment".

I observed David teach two lessons to two different populations of students. The first was a three-hour ninth grade geology class framed by three questions about fossil fuel consumption. The second was a fifty-minute presentation called, "Can Coal Be Clean?" that he gave as a guest speaker to two AP Environmental Science classes. Both lessons centered on an activity examining carbon flows between the atmosphere, geosphere, biosphere, and hydrosphere. Though the activity was designed with an eye towards the current GPS, it anticipated the NGSS focus on systems and system models. In fact, it went beyond the NGSS, which, despite their emphasis on systems and system models, make no mention of stock and flow diagrams.

Ninth Grade Geology

"We need to kind of change how the economy works."

David's preparation for class was intense and focused. When I arrived 20 minutes before class was to start, he was setting up materials for the students to use, and did not engage in small talk. Eight lab tables were arranged in pairs, so the students could sit in four groups of four. The front of the classroom was dominated by a whiteboard and a smartboard that David would control with a desktop computer. The day before David had told me that the district "cut [the science center's] budget by forty percent" in the last year, and a few details about the classroom suggested that greater efforts and/or funding could be committed to maintenance. A wall clock read 10:25, even though it was then 7:35. Three banks of florescent lights lit the room from above, and several of the bulbs were either dead or dim. Another bank was completely unlit, a fact whose significance would become clear an hour later.

Focusing questions.

"I don't want to focus just on climate change."

At 7:55, fifteen students (nine girls and six boys of diverse racial backgrounds) entered the room and promptly seated themselves. David started his lesson the Carbon Cycle by asking the students to write answers to three questions.

Why do we use so much coal, oil, and natural gas?

Why should we stop using fossil fuels?

How can we stop using fossil fuels?

Many districts explicitly require teachers to frame their lessons around 'essential questions'. Often teachers draw these questions verbatim from district curriculum guidelines, or sometimes almost directly from textbook headings. In David's case, he had invested considerable reflection on these questions, and spent about five minutes of our first interview sharing his thinking with me. At one point, he explained why the lesson didn't focus specifically on climate change:

> It bothers me that if you're not careful and you're teaching about climate change, and you show that fossil fuels produce climate change, and then [the students encounter] propaganda that says, "[Fossil fuels don't contribute to climate change]" then they think we're off the hook with fossil fuels. And so I want to make sure they know that there is a whole series of things in fossil fuels that you have to worry about.

David wouldn't mention the social and political controversy around climate science to his students. But he framed his instruction with the controversy in mind and described the controversy using a political term–"propaganda".

First Focusing Question: Why do we use so much coal, oil, and natural gas?

[The students] end up feeling hopeful that there's something [they] can do.

The class wrote for about ten minutes before discussing their answers to the first focusing question. After several students shared what they had written, David reframed the first question as two sub-questions:

Why do we use so much energy?

Why fossil fuels?

In answering the first sub-question, the class focused on energy use by consumers. One student mentioned agriculture, but no one mentioned industry.

In answering the second sub-question, David drew on the breadth and depth of his knowledge to integrate many seemingly diverse topics while engaging his students in a historical and scientific saga. The story started with the geology of Avery Island, Louisiana (where Tabasco Sauce is made), touched on meteorology, moved to whaling, and continued for five minutes until it got to the Wright Brothers and the development of modern aviation and transportation. As he spoke, the class was completely still unless he posed questions. Then one or two students, and sometimes the entire class, would call out their answers, before David continued. Though it meandered, the tale made two clear points: 1) Infrastructure is built over time on the foundations of existing infrastructure, and 2) Fossil fuels, particularly oil, are more energy dense than other fuels.

This example illustrates that David's most valuable resources are his own skill, knowledge, and personality. David quilted the tale from his own eclectic store of scientific, historical, and anecdotal knowledge; the threads that held the quilt together were spun in the unique workings of his own mind; and he presented the quilt to the class using his unique voice and mannerisms. I doubt that anybody could have systemically or explicitly aimed to teach David the background needed to tell this story, or that anyone could tell it as well as he did.

Next, David showed excerpts from the DVD, *Kilowatt Ours*, that highlighted how much energy is wasted in the typical American home (Barrie & Southern Energy Conservation Initiative, 2008). In the ensuing discussion, David said, "You can waste energy by using things you don't need, but you can also waste energy by doing things like […] using more lighting in the room than you really need". I looked up to the darkened bank of florescent lights, and realized that David had probably chosen leave the lights off to conserve energy, and maybe to set an example for his students.

Kilowatt Ours was a resource that David used in teaching the class. But David's clear understanding of how he wanted to use the DVD was crucial. As he told me the previous day:

> [Parts of *Kilowatt Ours* border on] propaganda. […] I like to use [a clip that] really shows how wasteful we can be with electricity. […] But most of what I show is this guy [demonstrating various ways to save energy in the home], and I want them to write down lots and lots of individual things that can be done to save energy. And [they] end up feeling hopeful that there's something [they] can do.

Second Focusing Question: Why should we stop using fossil fuels?

"That was probably the most effective graphic in there."

David invited the students to share what they had written earlier in the class. They brought up a number of issues, including air quality, the greenhouse effect, acid rain, and military conflicts. None of the students mentioned ozone, but David seemed to know that many people confuse ozone depletion and the greenhouse effect (see Hansen, 2010; Papadimitriou, 2004), and had prepared a powerpoint slide to address the misconception.

This elaborates my assertion that a teacher's most valuable resources are his or her own skill, knowledge, and personality. Experienced teachers often have a collection of resources that they have developed over the years. In this case, David had created a resource (the powerpoint slide) to address a common misconception. This reminded him to discuss that misconception, while providing him the means to discuss it with his students, even though none of the students expressed the misconception.

David mentioned several other problems linked to fossil fuels, before turning to the class's attention to global warming. He started by displaying the slide in Figure 11.

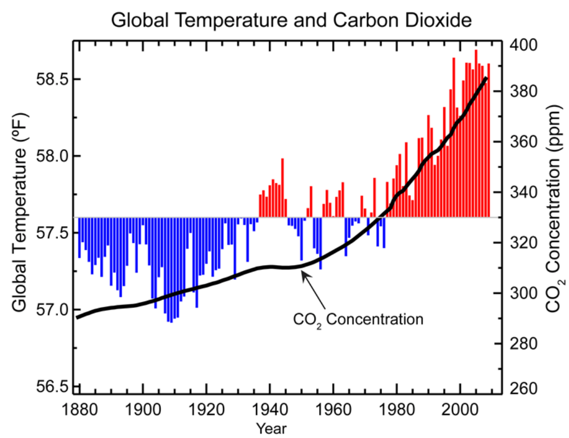


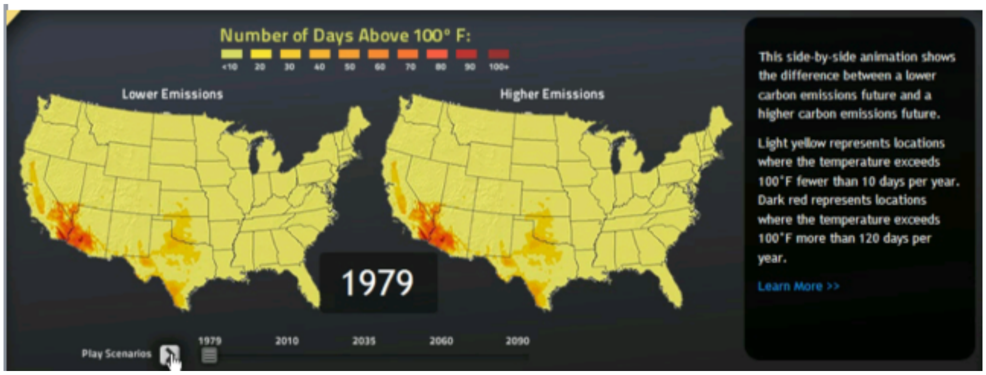
FIGURE 11
Powerpoint Slide: Temperatures and CO_2 concentrations since 1880.

This image is widely available on the Internet, and David could have easily found it using a search engine, such as Google Images. If so, his ability to discern accurate scientific images from less accurate images was an important resource as the website that posted the image or the search engine that found it. This discernment probably developed over his years of study and practice as a geologist.

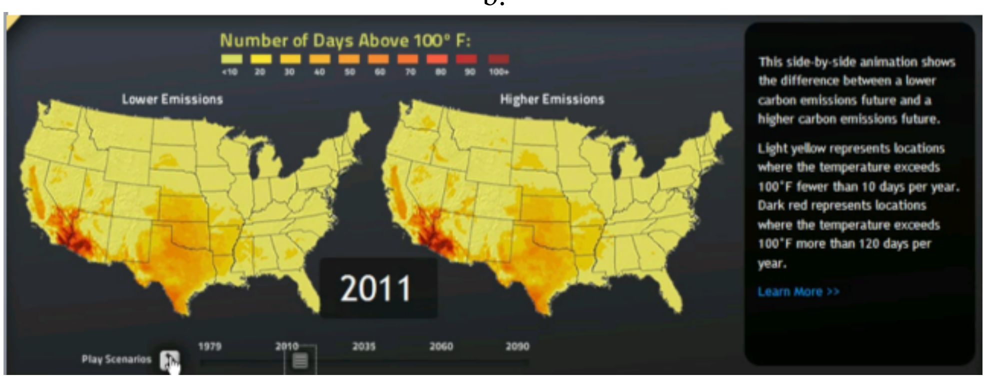
Next he displayed an image illustrating the Greenhouse Effect. He started by discussing the ice-albedo feedback, referring to it as a "vicious cycle". The image made no mention of feedbacks, so David's own knowledge and understanding of the climate system shaped his presentation as much as the visual resource he used.

He then showed a video clip displaying historical data on the number of days above 100° F for each year between 1979 and 2011 projected over a map of the US. Then a similar clip showed changes between 2011 and 2090 (See Figure 12).

a.



b.



c.

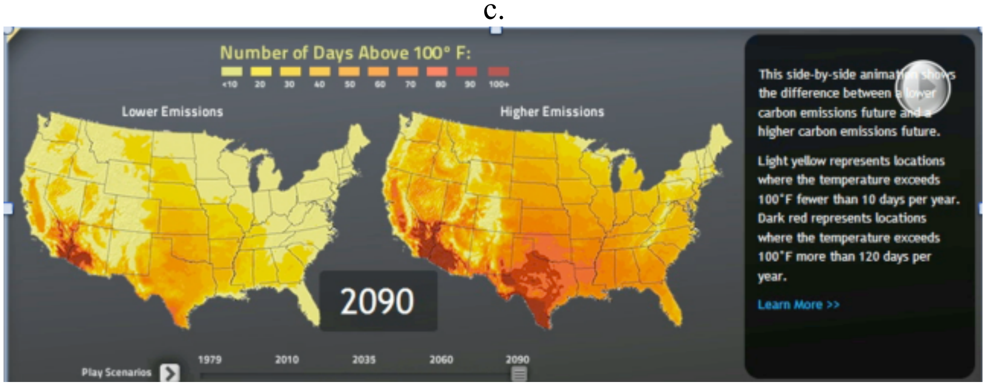


FIGURE 12

Screen captures of an animation showing the number of days above 100°F projected on a map of the continental United States. Figures 12a and 12b are based on historical data; in figure 12c, the left map uses the B1 scenario from the 2007 IPCC report, and the right map uses the A2 scenario from the same report ("Number of days above 100°F," 2014).

After showing the clip, he asked “Which United States do you want to live in?” referring to the two scenarios. Neither scenario looked great, and the students didn’t answer his question.

One student answered “Maine”.

Another added, “I wouldn’t want to live in Texas”.

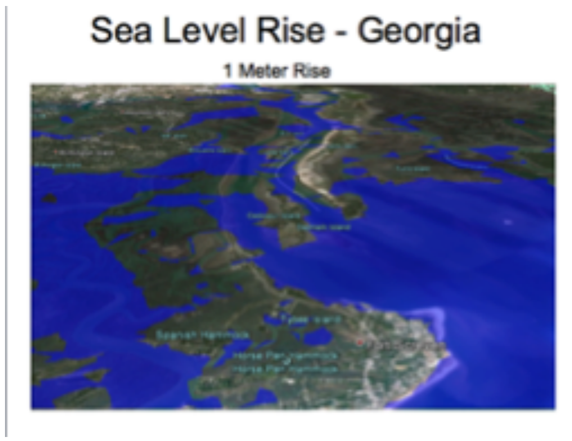
Another said, “I wouldn’t want to live in Georgia”.

Reflecting on the lesson later that day, David said, “That was probably the most effective graphic [in the powerpoint]. I believe it’s from Realclimate.org”. I couldn’t find it on realclimate.org, but it is on the home page of climatecommunication.org. It seems likely that David uses both sites to find videos and graphics to communicate with his students.

Next, he briefly discussed the reasons for sea level rise, and showed a satellite image of Tybee island as it looks today (See Figure 13a) followed by two images (See Figures 13b and 13c) showing how Tybee island might look with one- and two- meters of sea level rise.

a.

b.



c.

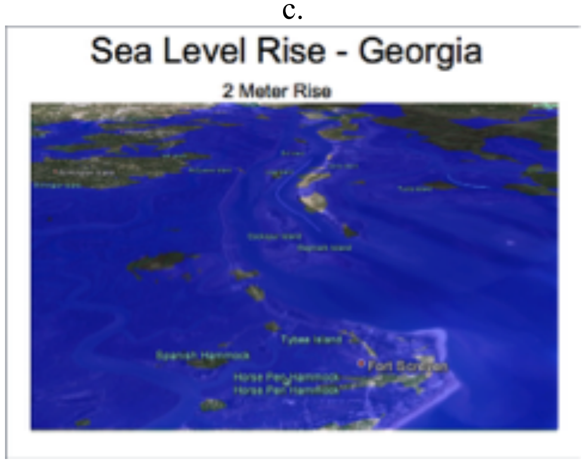


FIGURE 13
Powerpoint Slides: Satellite image of Tybee Islands Georgia (13a), and Google Earth images based on one meter (b) and two meter (c) sea level rises.

Later that day, David told me he generated images 13(b) and 13(c) using Google Earth. Google Earth is free, but it has a slightly steeper learning curve than other Google products. None of the other teachers in this study mentioned it to me, which supports my assertion that David's knowledge and skill allows him to make use of a broader range of resources than many other teachers.

While David focused on sea level rise in Georgia, he also connected it to Bangladesh (a poor and low-lying country that is especially vulnerable to sea level rise) and then back to practical and ethical concerns for Georgians. "Something like 80 million people live in Bangladesh, and […] they're going to become refugees, and might try to come here. So it can become our problem, besides the fact that you should probably feel some compassion for people in other parts of the world".

Next, David introduced an activity that asked the students to calculate how long conventional fossil fuel reserves will last at current rates of consumption and how high atmospheric CO_2 levels will be if all these reserves are burned. Each student got a copy of the handout (see Appendix C1); each table got a laminated 11x17 sheet; and David displayed a slide with the image on the laminated sheets (See Figure 14).

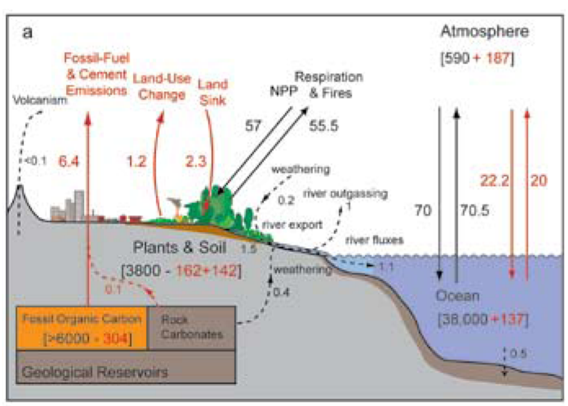


FIGURE 14
Diagram of the Carbon Cycle. (King et al., 2007, p. 22)

After David discussed how to read the graph, the students worked independently. The diagram from the *First State of the Carbon Cycle Report* (King et al., 2007) was an essential resource for developing this lesson. The free report is easily downloaded. In principle, any teacher with an internet connection could use it in their planning. But, given its length and technical nature, few teachers are likely to do so.

Change of Pace: Going outdoors

> *"It helps to do a variety [...] of things [...] including their own work time, but also to be able to go outdoors and look at the solar panel and then obviously there has got to be some lecture."*

After the students worked for around 15 minutes, David took the class outside to learn about the school's 8' x 12' solar panel. Later in the class, David would discuss how many panels would be needed to power the school, so the diversion would help show that solar energy alone cannot solve the problems linked to fossil fuels. The local power company had donated the panel to the school. David explained, "They wanted us to use it in education, […] and they probably wanted us to do this kind of education: Think realistically about solar and what it can do". David also said it was a successful activity, because it kept things from getting "too monotonous".

While they were outside, David showed off his hybrid sedan. He grinned as he lifted the hood to explain some of the energy saving technology engineered into the car, and then drove it a few feet, so the class could hear that the engine wasn't running. I doubt that David purchased the car as an instructional resource, but his commitment to energy conservation may have been decisive. Thus his personality was not only reflected in his evident enthusiasm for the technology, but in the fact that he had easy access to a hybrid car to show the class.

Returning to the classroom: Carbon-14 Dating

"The standards are supposed to be the minimum of what you're teaching."

After a short break, the students returned to class, and David asked them to "wrap up" their work on the carbon cycle activity. After ten minutes, he got the class's attention and asked a student to read, "Challenge number seven".

"Draw a graph with three lines showing the increase in carbon in the atmosphere in the last century coming from three different sources. Label each line as a source, and whether it is relatively high or low in radioactive carbon-14".

David led the class in a three-minute review of atomic structure, isotopes, and Carbon-14 dating. Then he led a discussion of the possible sources of atmospheric CO_2, and emphasized that fossil fuels, like other fossils, are low in Carbon-14, but that other sources of atmospheric carbon are high in Carbon-14. Over time, the level of Carbon-14 in the atmosphere has been rising more slowly than the level of carbon, indicating that much of the new atmospheric carbon comes from fossilized sources.[21]

Later, I told David how impressed I was that his students were learning how isotope ratios are used for radiocarbon dating of the atmosphere, as I had not seen the topic discussed outside of the scientific literature (e.g. Ghosh & Brand, 2003; Miller et al.,

[21] The low level of carbon-14 indicates that much of the new atmospheric carbon is geological in origin, but you can't rule out volcanism. When coupled with an analysis of the stable isotope carbon-13, you can reach the relatively firm conclusion that it is from fossilized material. Later I will point out one very small inaccuracy in David's AP Environmental Science presentation, and will claim it was the only scientific misstatement I noticed in three hours of taped interviews and five hours of recorded instruction. I don't consider this an inaccuracy, but a simplification for the sake of his audience.

2012). He agreed that some students have a better understanding of isotopes than others, but he didn't think I should be impressed, "They should have had it back in sixth grade when they studied Earth science before". David was no doubt correct that students should hear about Carbon-14 dating in sixth grade Earth Science. I would add that they should review it when learning about fossils in seventh grade life science and should study it in greater depth when exploring atomic structure in eighth grade physical science. Still, the topic doesn't appear in any middle school GPS. But as David said in an earlier interview, "The standards are supposed to be the minimum of what you're teaching".

Reviewing the stock and flow diagrams

"You guys could have grandkids that are alive in 2130, but even if you don't, um, you know."

The class quickly reviewed the first few questions on the handout about the stock and flow diagram, but when they got to the last two questions, which asked how long conventional reserves would last and how high CO_2 levels will rise if all of the conventional fuels are burned, David had a powerpoint slide ready (See Figure 15).

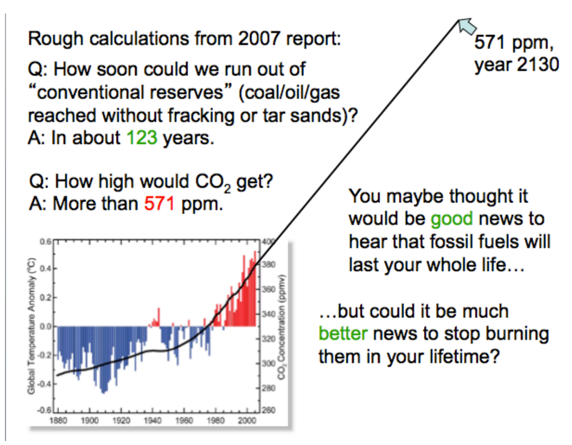


FIGURE 15
Powerpoint Slide: "Why should we stop using fossil fuels?"

In the ensuing discussion, he emphasized that both 123 years (for how long current reserves will last) and 571 ppm (for how high CO_2 levels might get) are underestimates, "because we've already started using unconventional fuels, like tar sands [and] fracking. […] So are we worried about running out, or are we worried about not stopping 'til we get there?"

A chorus of students replied, "Not stopping".

"Not stopping. We've got to find a way to stop before we get there. You're not going to be alive in 2130. I'm certainly not going to be alive. But should we care about anyone who's going to be alive in 2130?"

One student called out, "No", and a few others laughed.

"You guys could have grandkids that are alive in 2130, but even if you don't, um, you know".

This was the second time the ethics of climate change came up. The first time, David was lecturing, and simply told the class that they "should probably feel some compassion for people in other parts of the world". David's inability to explain why his students should care about unborn generations may reflect the fact that it stands outside his area of expertise–that he is not a moral philosopher. It may also reflect a deeper problem in modern American culture.

Third Focusing Question: How do we stop using fossil fuels?

I really want them to know what they can do.

David then turned the class's attention to the question of how to stop using fossil fuels, and asked them to take notes while watching a sequence from *Kilowatt Ours*

(Barrie & Southern Energy Conservation Initiative, 2008). The 20-minute sequence presented a straightforward solution to the problem: Step one is efficiency; step two is using green power. The movie discussed a number of energy efficiencies including compact florescent lighting, energy star appliances, and insulation. Later David told me that in teaching about energy efficiency, he was going beyond the standards "I really want them to know what they can do […] to reduce energy consumption, so that we've got a chance of dealing with the anthropogenic emissions that are in the standards".

Summing Up

I don't think this is insoluble, or I wouldn't be teaching you this stuff.

David gave the students 15 minutes to expand on the answers they had written at the start of the class. Then he started a five-minute summative discussion by saying, "We need to kind of change how the economy works", and discussed the possibility of shifting from an income tax to a carbon tax. He showed the slide in Figure 16, and asked, "Which of these renewable resources looks the least practical?"

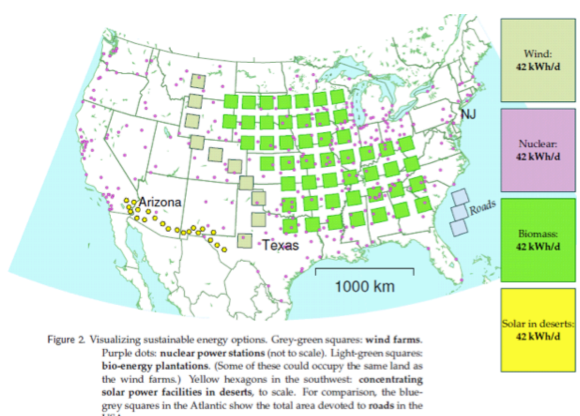


FIGURE 16
Powerpoint slide: Land needed to replace fossil fuels using sustainable energy sources. (From marketing materials for U.S. edition of MacKay, 2009)

Several students called out, “Biomass”.

He agreed that biomass was impractical. “Solar might be practical, wind might be practical, so I don’t think this is insoluble, or I wouldn’t be teaching you this stuff”.

A.P. Environmental Science

“Can Coal be Clean?”

I also observed David guest teaching two sections of A.P. Environmental Science at a high school that serves almost 2000 students. The first class had 32 students (19 boys and 13 girls), and the second had 28 students (16 boys and 12 girls). About 75% of the students in each class seemed to be white, and the non-whites seemed to be a mix of African-American, Hispanic, and South Asian. The two presentations were very similar. David told me that the presentation works best if he has an hour and half with a class, but the classes I observed were only fifty minutes long. The biggest difference between the two presentations was that David was more effective in time management with the second class. I will focus on the first presentation, and will note differences between the two presentations when they seem important.

When I entered the room, David seemed relaxed and ready for class to begin. His host teacher, “Mr. Robertson” greeted me and helped me set up. In the front of the room, a smart board displayed the day’s topic in large bold letters: “Can Coal be Clean?” The students were seating themselves in three long columns of black lab tables. When class started, David immediately framed the presentation around political rhetoric; minutes later, he hinted at one of his personal political goals. First, he introduced the question, “Can coal be clean?” by explaining that politicians often say they support clean coal. “So we're going to look at this: Is there a way to get energy from coal without having big consequences for the planet?" David was correct that the phrase "clean coal" is often used in political rhetoric. Given his broad understanding of issues related to fossil fuels, he may be aware that many people who think that coal is inherently dirty reply to the rhetorical linkage of the words "clean" and "coal" by asking the equally alliterative and more consonant question, "Can Coal Be Clean?" (e.g. Nijhuis, 2014; Snell, 2007).

Next, David referred to the first page of a handout (See Appendix C2) while displaying a slide that said, "Earth Science Literacy Principles". He told the class that the Earth Science Literacy Principles include some basic ideas everyone should know about the Earth, for instance so they can evaluate politician's claims about clean coal. In Georgia, he said, students take Earth Science in sixth grade, and most students don't take it after that: But AP Environmental Science students are lucky to be getting some high school Earth Science.

David later told me that once he retires "I want to [do more] things in the political realm", and that he may try to build a coalition to make Earth or Environmental Science a requirement for high school graduation in Georgia. The argument he presented for why the students were "lucky" to be taking Environmental Science could be used almost verbatim is discussions with educational policy makers.

What is coal?

"Coal's not very clean."

David then asked, "What is coal?" and displayed a slide illustrating how plants turn into coal. He explained that coal "is literally a fossil". He then indicated boxes of peat and coal samples on each table, “You’re literally looking at fossils. They may not be recognizable, because they’re so compressed. You’re looking at fossils of leaves and other plant material”. Then he discussed the peat and anthracite samples, and said “Anthracite is too valuable to burn for electricity. […] The other ones in there are either bituminous or lignite. If you picked those up, you would probably get smudge on your fingers, because coal’s not very clean”.

Within minutes, David had suggested an answer to the question that inspired the class, by having the students handle coal samples. Teachers can order similar kits from the American Coal Foundation,[22] and the first kit is free. The resource’s value lay less in the coal samples than in David’s using the samples to provide an eloquent answer to a simple question.

Environmental problems linked to coal

“So we do have to worry about mercury, carbon dioxide, smog and acid rain.”

In his ninth grade geology class, David discussed a range of problems linked to coal before focusing on climate change, and he explained his decision to do so in part as a response to political propaganda. In the AP Environmental Science presentation, he explicitly discussed politics, mentioning an international treaty, a Republican President, the Supreme Court, and in one class, citizen activism.

David stared the discussion of coal's environmental impact by displaying a powerpoint slide to highlight coal’s role in mercury pollution, acid rain, smog, and carbon dioxide emissions. Then he showed the slide in Figure 17, which made it clear that the problems associated with coal result from its basic chemistry.

[22] http://teachcoal.org/energy-and-you/coal-kit-order-form/

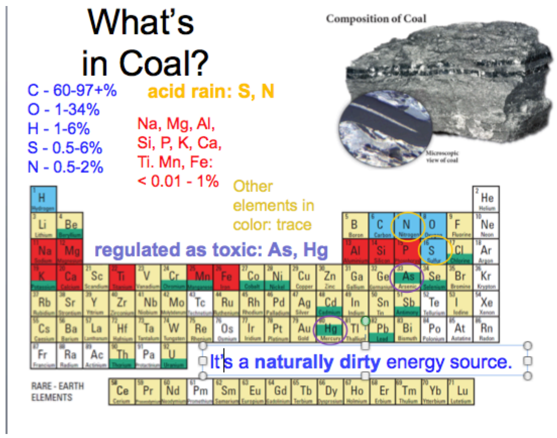


FIGURE 17
Powerpoint slide: Composition of coal.

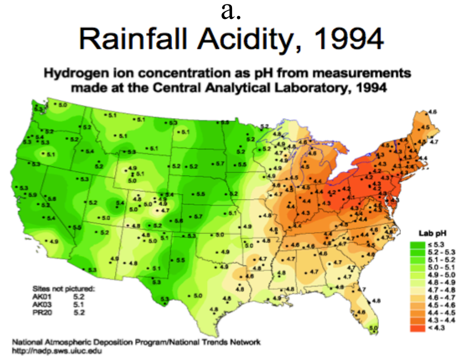
For several minutes, David led a discussion about coal's chemical make-up and the various pollutants linked to coal. He concluded by saying, "Coal is a naturally dirty energy source […], so the question is, 'Can we clean it up?'"

Then he moved on to the politics of cleaning up coal. He emphasized that a Republican President (Richard Nixon) signed the Clean Air Act. With the second class, he also discussed the importance of citizen activism. "Starting back in 1970, there were a lot of demonstrations. […] So the Clean Air Act was passed; the Clean Water Act was passed. A Republican president, by all this citizen pressure, was led to create the Environmental Protection Agency. And things started getting better". In both classes, he discussed the Supreme Court. He told the first class:

> In 2007, the Supreme Court ruled that carbon dioxide needs to be regulated under the Clean Air Act, because it impacts human health. […] If you get enough of it in the atmosphere: We'll get into some more of this later–it has to do with climate change. And the Supreme Court decided that the climate impacts human health, so it has to be regulated.

Next, he showed a series of three slides emphasizing that the Clean Air Act has already reduced pollution. He discussed acid rain in greater depth than other pollutants, and two slides (See Figure 18) elicited audible responses from the class.

a.



19b.

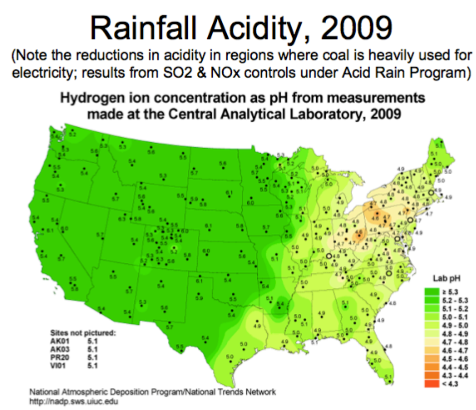


FIGURE 18
Powerpoint Slides: Reductions in Acid Rain Under the Clean Air Act.

Carbon Dioxide

"There's not much regulation of carbon dioxide yet."

David switched to a slide showing that CO_2 levels and global temperature were steady between 1000 and 1700 AD, when both started to rise quickly. "There's not much regulation of carbon dioxide yet". Then pointing to the slide, he asked, "Why did carbon dioxide in the atmosphere go up so much after 1700?"

One student called out, "Industry".

David agreed, and then discussed how ice cores are used to collect data on atmospheric temperature and CO_2. "People go to Antarctica and Greenland, and they drill down through the ice sheet, and they get this core of ice. This ice fell as snow at particular times, so they can look at one particular spot and say, 'this is the snow that fell in the year 1405'. In fact, they have it going back around 760,000 years. So how does that tell you what the atmosphere was like? Well, what do you think is making this ice cloudy?"

A couple of students called out, "Air".

David agreed, "Air. Air bubbles. So they look at those air bubbles and analyze the amount of carbon dioxide in the air bubbles […]. It turns out they can also look at oxygen isotopes in the air bubbles [sic], and estimate what the temperature was. And guess what? Temperature and carbon dioxide go up and down together for the last 760,000 years".

Having transcribed most of what David said over five hours of instruction and every word of three hours of interviews, I only noticed one misstatement about the current state of any scientific topic. It is a subtle point, but researchers use the oxygen isotope concentrations of the ice, not the air bubbles, as a temperature proxy. This exception proves the rule that David never made a significant misstatement regarding the current state of the science on any topic on which I feel competent to judge.[23]

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[23] I should point out that I also misspoke on at least one occasion–on a matter, which ironically, I discussed correctly less than 24 hours earlier. Still David was speaking much more than I was, and I am much less

The Greenhouse Effect and Stock and Flow Diagrams

"That's probably the most critical thing in my whole talk today."

At this point, the presentation resembled part of what David had done with his geology students. As with the geology class, he discussed the ice-albedo feedback before discussing greenhouse gases. Unlike with the ninth grade class, in discussing the importance of the greenhouse effect for life on Earth, he said, "We need a greenhouse effect on our planet. What concerns us is a runaway greenhouse effect. Venus had a runaway greenhouse effect". A week earlier, I had told David about how shocked I had been to learn that some scientists were taking the prospect of a runaway greenhouse seriously and specifically comparing the Earth to Venus (see Goldblatt & Watson, 2012; J. E. Hansen, 2009). Over lunch later that day, David confirmed that our conversation had informed his use of the phrase "runaway greenhouse".

I had become a resource that David used for his teaching. This realization brings my subjectivity into play in ways that may cloud both my judgment and my perceptions. It seems to me that David was explicitly raising the specter of Venus. The realization that I influenced David to bring up an aspect of the science that I find both highly speculative and highly alarming probably attracted my attention to something that most of the students may have barely noticed. I therefore leave it to the reader to judge what if any significance can be found in David's passing mention of a runaway greenhouse effect and Venus. I only note that none of the other teachers I observed even hinted at such a terrifying possibility.

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likely to spot my own mistakes than his. It also highlights the possibility that upon reflection, David might have realized the error himself.

David then introduced the activity with the stock and flow diagrams, but time constraints meant that the class had five minutes[24] to do an activity that his ninth graders worked on for twenty minutes. Accordingly, Mr. Robertson, David, and I all helped the students with their work. From my subjective position as a teacher, much of the assistance focused on figuring out which math operations to use for each question.

As David led a review of the worksheet, it became clear that he wanted students to be able to think through basic math problems. When they got to the last question, which required the students to use division, he asked, “So [how do you figure out] how long until we run out of conventional reserves? What do you do, do you multiply, divide? What do you have to do?”

The class was silent until one student answered very quietly, “Subtract”.

David responded, “So you have this much, and you take out so much per year, how do you figure out how long it will last? It’s probably worth working this one out with your teacher later, because you will need to know how to figure these things out for the AP exam. So […] what do you need to do to figure out how long it will last?”

“Divide”.

“Right you divide”.

Mr. Robertson said from the back of the room, “They will see something like that on the AP exam”.

“Right, you guys need to be able to think in these terms. Given a situation, how do you figure out the answers. That’s probably the most critical thing in my whole talk today–that you can do that. Unfortunately, we don’t have enough time for you to figure it

[24] The second class had ten minutes to work on the activity, and the review went much more smoothly than what I will describe below.

out on your own. So when you do that division, you find out that we have enough to last about 123 years".

Then he continued as he had with his geology class, showing the graph of projected CO_2 levels (Figure 15), the animation of projected warming for the US (Figure 12), and the simulations of sea level rise on Tybee Island (Figure 13). As with the ninth grade class, these students responded strongly to the animation showing projections of the number of 100-degree days overlaying a map of the continental United States (Figure 12). As the red patches spread across the map, an audible stir spread through the room.

Pointing to the map on the right, David said, "So a good part of the country, including Atlanta, looks like the Mohave desert does today in terms of the number of 100-degree days. […] And you guys are really going to make the difference in figuring out which place we're going to live in".

Carbon Capture and Sequestration

"Bottom line: Dirty coal is cheap; cleaner coal costs more."

For the next three minutes, David raced through eight slides on carbon sequestration that highlighted many of the difficulties inherent in the technology. He spent the most time talking about the cost of current clean coal technology, and the projected cost of carbon sequestration.

> Bottom line: Dirty coal is cheap; cleaner coal costs more. If you're just dealing with acid rain, coal is a little bit cheaper than wind. But if you look at putting carbon dioxide in the ground, then you're looking at costs that are comparable to putting photovoltaics on everyone's roof. So […]

> clean coal […] can be as expensive as solar. And solar's costs are coming down. So do we want to put a lot of resources into trying to get clean coal, or do we want to leave the coal in the ground, and try to find other things, like solar and wind?

David's presentation started with a discussion of political rhetoric. It ended with a discussion of the economics of coal, and an implicit call to devote more resources into researching and developing renewable energy, while leaving a huge reserve of fossil fuels in the ground.

Other Issues

I have focused on the first two research questions concerning what and how David teaches about climate change. I have touched on the other research questions as appropriate, but some topics did not fit into that discussion. In this section, I will focus more attention on the last three research questions, which look at resources as well as institutional and sociocultural factors that David reports influence his teaching.

Resources

"Dr. Shepherd would be very credible; you know he's a great speaker."

I've already discussed some of the government reports and academic books David used in developing his lesson plans, but these represent a small fraction of the resources he has used to further his own education. In the 1970s, he had already developed some expertise on the climate and energy policy. He named three books about the topic that he had read in that decade, and he also mentioned reading articles on climate science in both *Scientific American* and *Nature*. His interest has not waned, and in recent years, he has attended a number of science cafes sponsored by a local university as well as the 2012 Annual Meeting of the Geological Society of America.

In David's opinion, "We're awash in great materials for climate change education from NOAA, NASA, and then you can always go to SkepticalScience or RealClimate". Still, he felt that some of the materials were lacking, in particular, "When you Google for activities on the carbon cycle they leave out the geologic component". He said it would be helpful if materials could be developed "about the state of Georgia".

With his training and lifelong interest in geology, he wouldn't benefit from teacher workshops on climate science, but he said, "A lot of teachers could probably benefit from that". He also thought teachers could use "podcasts in a box". Experts in climate science could work with expert teachers to develop lessons about climate change. These lessons could then be videotaped and packaged with the materials needed to deliver the lesson, and the kits could be provided to teachers for classroom use. "Dr. Shepherd would be very credible; you know he's a great speaker".

Institutional Factors

"What an opportunity […] for everybody, for the school system, for the whole country."

David said he has "a really special job, a special opportunity". He reported that he enjoys "a lot of freedom" as a teacher, and that he and his colleagues "have been very well supported in doing our jobs by our immediate administration". His colleagues all have post-graduate degrees in their subject area.

> It's great […] to have somebody to consult with on any subject that you get curious about. Imagine having people who are basically university level academic people being in K-12 classrooms everyday. What an opportunity that is for everybody, for the school system, for the whole country.

Still he reported a number of challenges in dealing with the district administration, including significant budget cuts and threats of closure in recent years. Some of his colleagues have left because of these challenges, and "we've lost several of our best staff".

Sociocultural Factors

"I've been a little disappointed in particular about climate change."

A large body of literature discusses diversity as a challenge for science teachers (e.g. Bryan & Atwater, 2002). David's workplace serves an entire district, so the student population is more economically, educationally, and ethnically diverse than most schools. But David sees diversity as more of an opportunity than a challenge:

> One of the really cool things about [the science center] is that these kids really get to see the other kids from all over the county and they spend a whole semester [together]. And [the last day is] wonderful. When you see them going off on the buses, and everybody is crying […], and they've made some really lasting friendships with kids from totally the other end of the county. It's a really wonderful thing. So, the kids that are coming from the poor schools get to see […] what they've got to get ready for, for college.

We didn't discuss ethnic diversity in depth, but David said he found personal satisfaction in working with diversity in learning skills.

> I feel that I'm doing more for the kids than I was back [when I started]. Back then I'd say that there were always two or three kids in the class that I was just in perfect tune with and of course, they were the gifted kids or whatever. And then there was the rest of the class that I was okay with, you know? Now I feel like maybe I'm more in tune with more of the class.

Both of the lessons I observed centered on an activity in which the students were asked to determine how long current reserves of fossil fuels could last. The students needed to figure out that they could do this by dividing the size of the reserves by the rate at which they are being used. Many students struggled to understand that this was a division problem. David did not express frustration that his students hadn't mastered elementary school math, instead he spoke at length about this aspect of the lesson, emphasizing that the students "desperately need [to learn] whether to add, multiply, subtract, or divide to get certain answers". He concluded the discussion by saying that teaching "feels more fun" now that he is connecting with the less gifted students.

David's teaching responsibilities encompass one-week courses and classroom visits, so he doesn't have the opportunity to develop long-term relationships with students. Still the small class size in the one-week course, "seventeen kids max", allowed him to work with individuals who need extra help.

Despite the high level of respect David voiced for his colleagues, he told me, "I've been a little disappointed in particular about climate change". He said, "One reason I [focus on climate change, is that] my colleagues [don't think] this is something really important that we need to educate kids about". The ninth grade geology course is offered as part of a semester-long program in which the students spend one-week studying each of a variety of topics. Years ago, the staff discussed how they could tie the various courses together, and David argued for Earth Systems.

> I've felt frustrated that almost at every turn […]. People are too comfortable with, "Hey, this is what I like to teach in [ninth grade], this is what's fun in my area of the sciences". They are not so interested in, "Hey, these kids really need to understand how the Earth works as a system". [...] So, that's my frustration with my colleagues, […] because they're not going to get it anywhere else in high school".

Case Summary

"I have a great time; I really enjoy my work."

Dr. Woolf is a particularly interesting case because of: 1) his subject knowledge, 2) his unique work situation, 3) his involvement in drafting state and district standards, and 4) his conviction that students need to understand how the climate interacts with the rest of the Earth, including human society. In discussing the role of human society within the climate system, he did not shy away from discussing politics or economics, and even hinted at ethics. Both of the classes I observed were framed around questions, and while he encouraged the students to think about these questions, he offered his own answers to each of them. Both classes focused on fossil fuels, and David pointed to climate change as one issue related to fossil fuels, but he also discussed acid rain, mercury poisoning, smog, particulates, and other problems. In discussing the climate, he emphasized Earth systems science, drawing the students' attention to stocks of carbon within the hydrosphere, the geosphere, and the biosphere, while focusing their attention on the atmosphere. He showed how human society interacts with the rest of the Earth system by altering the flows between the various stocks.

David drew on a range of resources in preparing his lessons. The most valuable were his personal stocks of knowledge and skills, which in turn gave him the ability to draw on other resources, including documents written for professional scientists. His own personality is also a resource, and his personal growth as a teacher has enabled him to "connect with" a large number of students, including those who were less naturally gifted in science than he was as a young person.

Institutional and sociocultural factors influence his teaching. He was very familiar with the GPS and the SLOs having helped draft them, but he felt that they didn't tell him what he should teach. Instead they set a minimum requirement, and he enjoyed freedom to decide what he would do beyond this minimum. He voiced a high level of respect for his colleagues, and considered them an important resource, yet he voiced frustration that they don't consider Earth Systems science as important as he does. He enjoys "the energy [he] get[s] from being with kids", but unlike most teachers, he doesn't have the opportunity to build relationships with his students over the course of an entire school year.

David is an exemplary case for his level of content knowledge. None of the other teachers I observed came close to David's level of content mastery, but each was exemplary in his or her own way. Next, we will turn to Jeff Zale, who showed exemplary skills as a teacher.

Case Two: Dr. Jeff Zale – Continual Improvement

"THE DOCTOR IS IN!"

Jeff Zale works in a suburban high school that serves over 2000 students, where he teaches oceanography, meteorology, and physics as well as serving as Science Department Head. My study of Jeff's case looked at four-days when his oceanography class was studying how weather and climate influence the ocean. This investigation prompts me to make assertions relevant to each of the research questions.

Research Question One (RQ1): What do teachers teach about climate change?

a) Jeff presents both sides of the global warming debate.

b) He taught his students to distinguish between the greenhouse effect, global warming, and climate change.

c) He taught that climate change can refer to global warming or global cooling.

d) He taught that the oceans moderate global warming.

RQ2: How do teachers teach about climate change?

a) Jeff asked his students to think through the science for themselves.

b) He committed over two hours of class time to a lab about melting ice.

c) He often discussed the question of whether humans impact the climate system.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) Jeff's most valuable resources are his own skill, knowledge, and personality.

b) He engages in a process of continual improvement as a teacher, and over twenty-five years has developed into a highly skilled teacher.

c) He relies on a variety of media sources to learn about climate change.

d) He uses his textbook to learn about climate change.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) Jeff was attentive to the unit's standard, which specifies global warming, but he also discussed global cooling.

b) Because of time restraints and conflicting priorities, Jeff may reduce his coverage of climate change in future years.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) Jeff is deeply embedded in his school community, having taught there for 23 of his 25 years of teaching.

b) The community tends to be political conservative, and Jeff's efforts to teach both sides of the climate debate have not generated any negative feedback.

Synopsis

Jeff demonstrates an unusually high level of teaching skill. He has been teaching at the same school 23 years. His apparent contentment does not imply complacency. He earned a Ph.D. while teaching full-time and spent part of his summer vacation attending a workshop on teaching about climate change. In our interviews, he often reflected on how he could improve his teaching practice.

Jeff taught 4 ninety-minute classes touching on the question of "How do the oceans influence global climate change?" as part of an oceanography course. The classes included a mix of activities ranging from short powerpoints/lectures, a lab, several teacher-led discussions, and group work in which the students made informative posters about global warming.

Setting

Jeff was relaxed when I arrived for my first classroom observation. I had been to his classroom once before, yet he met me in the office and escorted me though the cavernous hallways. Many of the students we passed greeted him, calling him “Doc” in a tone that usually struck me as respectful and affectionate. Upon entering Jeff’s classroom, the first thing you see is a large painting of his college mascot dressed in blue doctor’s scrubs, wearing a stethoscope, and holding a sign announcing, “THE DOCTOR IS IN!” Jeff's classroom is large, well-lit, clean, and well-equipped. Desks were arranged in four rows with seats for 36 students. To the left, a door opened up to a prep room that Jeff shared with one other teacher; it is larger than Dr. Woolf's classroom and filled with supplies. A bank of three whiteboards dominates the front of the room, and a projection screen covers part of the rightmost board. Jeff has decorated the room with mementos from teaching career, including the Teacher-of-the-Year Plaque he had won ten years earlier, and dozens of photographs of teams he has coached.

Introducing The Global Warming One-Pager

“I basically tell them […] to find information that’s on both sides of the argument.”

I was observing another teacher when Jeff introduced the “Global Warming One-Pager”, but he provided me a copy of his powerpoint with embedded audio from the class presentation as well as copies of the handouts he used (See Appendix D1). The assignment asked students to work in groups of three or four to make informative posters about global warming. In an interview, Jeff explained that he saw the assignment as an opportunity for students to explore both sides of the global warming debate.

> I basically tell them […] to find information that's on both sides of the argument. Because if I were to present only one side, then I don't think I'd be doing justice either way. […] I try to stay out of it somewhat. […] That way, when they find out what [scientific research has] uncovered, they can take the data that was discovered from the [research], and try to synthesize it themselves.

I am asserting that Jeff "presents both sides of the global warming debate", but I have not specified what I mean by 'the global warming debate' or by 'both sides'. Jeff often discussed climate change by referring to contrasting viewpoints on specific issues, and I will highlight those. In the next section, we will see that Jeff said the debate is taking place among politicians and within the media, and that for his students to understand the debate, they need to clearly understand the language being used.

Distinguishing global warming, the greenhouse effect, and climate change

"I want you guys to be way smarter than the people in the news and the politicians."

During the same class period that Jeff introduced the Global Warming One-Pager, the class reviewed the student's responses to a handout about global warming (See Appendix D1). The first question asked students to distinguish global warming and the greenhouse effect. As Jeff explained it to the class,

> [*Global warming* is] a gradual warming beyond the average temperature of our planet. […] The *greenhouse effect* keeps our planet from being

frozen [and is naturally caused by greenhouse gases, including] carbon dioxide, water vapor, and methane.

He also asked the students to distinguish climate change from global warming, and explained, "I want you guys to be way smarter than the people in the news and the politicians. When you listen to the news, you'll hear people talk about 'global warming', 'the greenhouse effect', and 'climate change' as though all three are the same thing".

Before proceeding, I want to remind the reader of how I defined global warming and climate change in chapter one:

> *Global Warming:* An increase in average global surface temperature […].
>
> *Climate Change*: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties […]. (IPCC, 2014a, p. 3).

In the next section, we will see that Jeff presented a narrower, though arguably more intuitive, conception of climate change. This conception will also frame one of the dichotomies that Jeff presented in the two-sided debate about global warming.

Global Cooling

"This standard basically slants it to one viewpoint."

Jeff started the discussion of climate change by saying, "So if the planet can get warmer, that also means it can sometimes get cooler. […] And it sometimes [gets much cooler], and we call those big changes 'ice ages'."

In an interview, Jeff would later explain his reason for emphasizing global cooling along with global warming:

> Our standard is actually specially says, “How do oceans influence the greenhouse effect and global warming?” So they kind of pigeonhole you a little bit in that you can’t just talk about any kind–I mean, I know, global warming is climate change–but I know that sometimes the climate gets warmer and cooler. […] This standard basically slants it to one viewpoint.

In a later interview, Jeff considered how he might modify the “Global Warming One-Pager” when he teaches the course in the future:

> I don’t know if I want to call it “The Global Warming One-Pager”. I think I just want to call it a “Climate Change One-Pager" and let them go basically one way or the other. I might even [ask them] “What do you think has to happen for our climate to get warmer? What do you think has to happen for our climate to get cooler?” And let them go both ways with it. […] If they want to throw human interactions in there they can, or if they want to stay natural they can.

In addition to the warming-cooling dichotomy, in the last sentence of the quote, he mentioned another dichotomy between ‘natural’ and ‘human’. This second dichotomy would be emphasized later in the unit.

Ocean Acidification

“OK. I'm not going to tell you what that means now.”

For the next three minutes the class discussed how global warming and the oceans influence each other. One student suggested that ocean acidification was related to global warming.

Jeff responded, “OK. I'm not going to tell you what that means now”.

Earlier, I had asked Jeff if he covered ocean acidification, and he said, “In this unit, not so much, because the next unit after this one is the chemistry of sea water, so then we do get a little bit about the pH, and we talk about ‘Why would pH change?’”

In an oceanography class, it's natural to discuss ocean acidification in the context of sea-water chemistry. If climate change is understood in the context of CO_2 emissions and global environmental change, then ocean acidification is related to climate change. This was the only time I heard the topic mentioned in any of the classes I observed. The question of how ocean acidification can best be integrated in the existing science curriculum merits further discussion.

Review and Lab

“[…] the difference between discipline and routines, between behavior management and classroom management.”

Before the students arrived, Jeff had posted the day’s essential question, the GPS standard being addressed, the day's agenda, and the due dates for upcoming assignments. Thirty-three students (30 seemed white, with an even mix of boys and girls) entered the classroom, took out their books, and quietly chatted with their neighbors. Jeff started class very efficiently, and within two minutes, he had introduced me, made a number of other announcements, and gone around the room with a stamp pad to check that each student had done his or her homework, and briefly chatted with some of the students as he did so. Even though these tasks were done with amazing dispatch, his tone was relaxed, and he even made a few jokes during the announcements.

As a teacher, I had a strong subjective reaction to Jeff's classroom management skills. The next day, after an interview–but with the recorder still running–I complimented him, and specifically mentioned how quickly class got started. After a short demurral, he said, "I teach at the new teacher institute [for my] county. […] As an instructor, [I've become much more aware of] the difference between discipline and routines, between behavior management and classroom management".

Jeff's district employs almost 6000 teachers, and Jeff's teaching skill is so highly regarded that the district asks him to teach new teachers. But this hasn't make Jeff complacent. Instead it has inspired deeper reflection on his own teaching practice. Once again, I find that a teacher's most important resource is his or her own skill, knowledge, and personality. In Jeff's case, his skill as a teacher, and his personal drive to improve his teaching skills represent two valuable resources. While I suspect Jeff takes these resources for granted, his district seems to understand their value.

Homework review

"[…] water vapor, methane and carbon dioxide all come from natural processes, as well as, possibly, human processes."

Jeff had projected a powerpoint slide entitled "Greenhouse Effect", that contained three questions:

1) How is it created?

2) What gases are involved? Why these gases and not others?

3) Explain what is meant by the concept of the Earth's energy budget?

Jeff rolled a die to randomly pick a student to call on and asked his to answer the first question.

The student provided a brief answer, and Jeff used the opportunity to speak about the greenhouse effect in greater depth than he had on the earlier recording.

> It's a natural phenomenon. So there are gases in our atmosphere that naturally do this. Some of the energy from the sun comes through as light. And as it's reflected–or as it's emitted after it's absorbed–some of the gases in our atmosphere don't just capture what's leaving. Think of it like this: When you're walking around and you see light being reflected, it's also absorbed by the Earth, and being emitted too. If we had special glasses we could see the energy that's being absorbed in other spectra.

This was not the class's first discussion of the greenhouse effect, and they were reviewing a homework assignment, so the students may have understood what Jeff was saying within the larger context. But Jeff's discussion of optics, including his mention of "special glasses", may have confused many students.

Jeff then rolled the die again, and called on another student to answer the second question about identifying greenhouse gases. In the ensuing discussion, students mentioned water vapor, carbon dioxide, methane and nitrous oxide. Jeff added CFCs to the list, explaining, "CFCs are the only one that we've talked about that are purely from human sources. But water vapor, methane and carbon dioxide all come from natural processes, as well as, possibly, human processes".

I have asserted that Jeff frames his discussion of climate change around dichotomies, including a natural vs. human dichotomy. This dichotomy interacts with another one, which I will call certain vs. uncertain. CFCs *certainly* come from human sources, while other greenhouse gases are *certainly* natural. Humans may also contribute to the levels of "natural" greenhouse gases, but this is *uncertain*.

Next he turned to question three, "Explain what is meant by the concept of the Earth's energy budget?"

After a student gave a brief response, Jeff asked the class, "What do you think happens if it's cloudy at night in terms of the temperature?"

When no one responded, Jeff said, "Talk to the person next to you. Let's say it's clear all day, and at night the clouds suddenly come in. What do you think that will do to the ability of the planet either to cool off or warm up?"

After the students talked with each other for around thirty seconds, Jeff and the class discussed various possibilities, until Jeff explained:

> Once the sun goes down, all that heat that's been building up during the day starts to radiate away, but if you move something over the top […] it absorbs it, and re-radiates it back to the planet. So clouds can have a warming effect. They can prevent some of that energy from radiating into space. So that's a microcosm of the greenhouse effect. Certain gases in the atmosphere capture some of that energy, and keep it from leaving. And as [your classmate] was alluding to, we have a certain amount of energy that comes in and a certain amount that goes out, and if those aren't in balance, you'll get either warmer or cooler.

Jeff's analogy between nighttime clouds and greenhouse gases seemed very clear to me. In addition to teaching oceanography, Jeff teaches meteorology. I have asserted that one of Jeff's most valuable resources is his own skill and knowledge, and I suspect that his experience teaching meteorology informed this analogy. In fact, he included a short lesson on meteorology to make the analogy.

Although it wasn't one of the three questions posted on the powerpoint, Jeff also asked the class to compare and contrast global warming with the greenhouse effect. Much of this reiterated what was said before, but, for the first time that I observed, he stated that global warming is in fact occurring, but added that there was a debate about the cause.

> One of the things [the greenhouse effect and global warming] might have in common is the gases involved. The gases that give us the greenhouse effect are also the gases that are up for debate over whether these are what's causing the planet to get warmer. […] Some people say that global warming is related to human activity, because we are adding those gases to the atmosphere beyond the natural amounts. So they're basically saying that the gases that cause the greenhouse effect can also cause global warming.

Sea Ice Lab

"I've [learned that I can have] up to ten hot plates."

The final hour of the class was devoted to a "Sea Ice Lab" (see Appendix D2). The students worked in eight groups of four or five students each. Each group placed ice and liquid water in a 600 ml beaker.

Great Lakes Group: 100 ml of ice and 300 ml of **fresh** water.

Arctic Lakes Group: 200 ml of ice and 200 ml of **fresh** water.

North Atlantic Group: 100 ml of ice and 300 ml of **salt** water.

Arctic Ocean Group: 200 ml of ice and 200 ml of **salt** water.

Each group recorded the initial temperature of the liquid, and then put their ice/water mixtures on a hot plate, and recorded the time needed to melt the ice, the water temperature when the ice was completely melted, and the water temperature at an equal time intervals after the ice had finished melting.

Jeff introduced the lab by explaining:

> When people talk about global warming, they always talk about melting sea ice. We've already discussed how if the ice in the oceans starts to melt, that's not going to cause a dramatic increase in sea level […]. But does the ice in the ocean have any other influence on the climate? If you were to melt all the ice, what would that do to how our planet heats up and cools off?

In discussing David Woolf's case, I highlighted a subtle misstatement about stable-isotope studies, so that the exception might prove the rule that David provided a very accurate picture of the current state of climate science. In general, I am not applying the same critical eye to Dr. Zale's statements. In this case, Jeff devoted two hours of class time to conducting and analyzing a lab about melting sea ice. In framing the lab by saying, "if the ice in the oceans starts to melt", he implied that it isn't already melting–or if it is, it isn't melting quickly enough to be noticeable. A strong scientific consensus exists that both the area and volume of arctic sea ice are declining very rapidly, and given the importance of the ice-albedo feedback, this is one of the most worrying aspects of the unfolding process (Stroeve et al., 2012; Walsh, 2013).

After Jeff explained the procedure and offered a few words of precaution about dealing with the hot plates, the students went to work. They had 45 minutes to complete the lab. Jeff stood quietly scanning the room, occasionally dropping in on particular groups and answering student questions. The students seemed to understand what they needed to do, and the class was calm, though some of the students didn't seem engaged in the lab itself. From my subjectivity as a teacher, it seemed that the lab was too straightforward to justify four- or five-student lab groups.

The next day, Jeff and I had a one-hour interview about the lab and ensuing analysis. This interview was one of the main data sources that moved me to assert, "Jeff engages in a process of continual improvement". In fact, I have come to believe that this process is such a deeply ingrained habit that it constitutes part of his personality, and therefore also motivates my assertion that his personality is an important resource.

Jeff often discussed how the class could be improved, when I had asked a completely different question. For instance, when I asked *how he felt* while teaching the class, he answered, "I don't want to be entertaining just for entertainment's sake but it would be nice for me to probably preface this [with] a hook".

At many points, his drive for improvement engaged my subjectivity as a teacher, and I would step out of the role of interviewer, and suggest improvements, as in this exchange.

Len: How do you think the class went?

Jeff: I think next time I do this I'm going back to my previous use of larger pieces of ice that can't melt as quick. [He continued to speak about the ice, telling me how he had done it in the past, and explaining why he had changed his procedure.]

Len: […] Is there a way you could maybe measure a hundred mls of water ahead of time and freeze it inside a ziplock bag, and then distribute the bags?

Jeff: Yeah, yeah.

Len: Like, 'this is a hundred mls right here.' […] That might not be too hard to do.

Jeff: As long as I can get it so that size-wise it can fit into a beaker, then yeah…

Len: And what if….

Jeff: Freeze it in dixie cups.

Len: Yeah, something like that.

Jeff: Yeah, that way we know we've got exactly the amount we need…

Len: And the surface area too. So anyway, is there anything else you would have changed?

Not only did my subjectivity move me out of my role as interviewer, but our shared subjectivity as teachers who seek to refine our lab procedures influenced my follow-up question as I re-assumed my role as interviewer. Instead of returning to the protocol, I asked what else he might change.

Later, I suggested an improvement without any prompting, "I'm wondering why you didn't have [smaller] groups".

Jeff answered, "Electrically speaking, if you have too many hot plates–I've blown the circuit before. So I've [learned that I can have] up to ten hot plates".

The school's infrastructure is an important resource that teachers rely on, sometimes without thinking. In this case, Jeff used the school's electrical infrastructure to almost its full capacity.

Global Warming and Analyzing Sea Ice Lab

The next day's agenda was written on the white board when I arrived. The class would consist of: 1) a warm-up activity reviewing basic ideas about global warming, and 2) a discussion of the previous day's lab activity. There would not be enough time for item (3), "Complete Global Warming One-pager".

Reviewing Global Warming

"If you burn gasoline or natural gas, one of the byproducts is carbon dioxide."

At the start of class, Jeff pointed to the Powerpoint slide displaying three questions:

1) How is global warming different from the greenhouse effect?

2) Give several reasons why the oceans are important to the global warming discussion.

3) How do clouds make our planet warmer? How do they make it cooler?

In discussing question (2), Jeff focused on phytoplankton and water as natural sinks for CO_2, which led him to ask, "What are some natural sources of carbon dioxide?"

After students mentioned respiration and decomposition, Jeff expanded on their answers, saying, "OK. Respiration. Forest fires. Volcanoes. So there are natural sources of carbon dioxide. So carbon dioxide has been in our atmosphere for thousands and thousands of years, way before humans got really involved. So from your research, how do humans get involved in this?"

A student said, "Burning fossil fuels".

Jeff elaborated, saying, "Burning of fossil fuels. If you burn gasoline or natural gas, one of the byproducts is carbon dioxide". In over four hours of direct and recorded observation, this was the only time I noticed Jeff mentioning fossil fuels.[25]

Lab Review

"There are lots of possibilities, and that's what makes our Earth so complex."

Jeff then asked the students to get ready to discuss the sea ice lab and lifted the screen to reveal the data students had recorded the previous day. The discussion focused on answering several questions included in the handout (see Appendix D2). Jeff started by focusing the class's attention on the temperature change in the fresh water before the ice had melted, and asked, "What does that tell you guys about the influence of ice in fresh water when it comes to heating up the water?"

One student answered, "It slows it down".

Turning to the four salt-water groups, he pointed out that one group's data differed from the other three, and said that if you ignored that one group, the salt-water groups also found that the water heated much more slowly before the ice melted. He then

[25] During the member check process, Jeff said that he discussed fossil fuels while showing a powerpoint slide. I asked him to let me know when he brought it up, so I could include it in my narrative. He didn't respond, and I couldn't find the slide in the archive of powerpoints he had provided me. This was the only time *I* noticed him mentioning fossil fuels. I missed two class sessions, and Jeff only recorded portions of those sessions for me to analyze. Jeff provided me the powerpoints early in my observation process, and I don't have copies of any powerpoints he revised or developed over the course of the unit.

instructed the class to write down their answers to question five, "In general, what effect does sea ice have on the rate at which ocean temperatures change?"

Jeff walked around the room as the students wrote and recommending that they, "support your answer with some data". When most of the students seemed finished, he summed up by saying that there might be slight differences between fresh and salt water, but "I hope you all saw that whether its fresh or salt, the presence of ice slows down the temperature increase".

He then asked the class to think about question six, "How might glaciers, ice packs, and sea ice influence the climate?' […] This might be more of an opinion, but think of some evidence that you might use to support it. […] There's not just one right answer".

After about two minutes, he led a full group discussion, explaining, "There are lots of possibilities, and that's what makes our Earth so complex". Still, he indicated that sea ice might moderate any temperature increases, but if it were all to melt, the ocean's temperature might start to rise more quickly:

> If you melt too much of [the sea] ice, then the overall temperature of the water could start to go up faster. So it may not make a huge difference at the beginning, but without the sea ice, that incoming heat would make the temperature go up even faster.

This seemed to be the main point of the lab. I was struck by the fact that I have never seen the point emphasized in the scientific literature on climate change, where the ice-albedo feedback is more widely discussed than the latent heat capacity of ice.[26]

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[26] Later, in my subjectivity as a science fan, I did a back-of-the-envelope calculation and convinced myself that the latent heat capacity of ice is much less important for the dynamics of the climate system than the ice-albedo feedback (See Appendix D3).

Jeff then raised several issues that are often discussed by climate scientists, including changes in ocean salinity, ocean circulation, and precipitation. He mentioned the ice-albedo feedback in passing, but he framed this as a cause of global cooling, not as a feedback that accelerates both warming and cooling, “When sunlight hits ice, it’s reflected. So sometimes the ice can have a cooling effect, because if the energy’s not absorbed it’s reflected. So sometimes you can actually talk about global cooling if you have a lot more ice”.

The discussion lasted about five more minutes, and touched on a lot of possible impacts of melting sea ice in rapid succession. Some of these impacts might be expected accelerate warming; some might mitigate it; and some might counteract it. I had the sense that most students would have concluded that there are so many potential impacts from melting sea ice that it would be almost impossible to make any reliable predictions.

Changing Climates …. Naturally

"[…] we’re going to look at the fact that it has nothing to do with what humans have been doing.”

The next day, Thursday, I was observing another teacher when Jeff presented a powerpoint entitled, “Changing Climates… Naturally”. Most of the class session was devoted to administering a quiz, and Jeff provided me with an audio recording of the fifteen minute presentation embedding within a copy of the powerpoint, which allowed me to hear what he said as he displayed each slide. The recording started with a slide on plate tectonics, and Jeff explained:

> The climate on our planet changes naturally. […] We're going to look at why it's been different [in the past], and we're going to look at the fact that it has nothing to do with what humans have been doing.

Turning to plate tectonics, he pointed out that as the continents change latitude, the climates on the particular continents have changed. He offered Australia as an example, since Australia was once near the South Pole, it used to be much colder than it is now.

Milankovitch Cycles

"I'll do a lot of image searches […]."

Next Jeff discussed Milankovitch cycles, and explained, "The idea is that the Earth doesn't always do the same thing in the solar system all the time". After briefly discussing eccentricity and precession, he defined obliquity as "the change in the amount of tilt", and asked, "Do any of you guys know what our tilt is right now?"

One student answered, "Twenty three point five".

And then he asked, "What if it went from twenty three to fifteen? Talk to your neighbor and decide, what would happen to the climate–lets just start in Georgia–if the tilt went from twenty three to fifteen".

After around ten seconds, he called on one student who said, "Warmer winters".

"OK, we could have warmer winters. What about our summers?"

Another student called out, "It would be more even".

"Yes, we would have more even heating year round. […] It would be kind of like being in Southern Florida".

Most climatologists think about the Milankovitch cycles in the context of the ice-albedo feedback. The most widely used metric is insolation at 65°N on the summer solstice. When Arctic summer insolation is low, the ice retreats less during the summer, and the northern hemisphere ice sheets tend to grow. This in turn impacts the global climate because of the ice-albedo feedback, leading to a global ice age. (For a number of reasons, the Antarctic ice sheets were relatively stable during the Pleistocene, so the level of Antarctic insolation was much less important.) It's almost impossible to say how the Earth might change if the tilt were reduced to 15°. During the Pleistocene, it varied between 22.1° and 24.5°, and low obliquity was linked to ice ages. A snowball Earth could not be ruled out under such an extreme change in obliquity.[27]

Next, Jeff showed the slide in Figure 19.

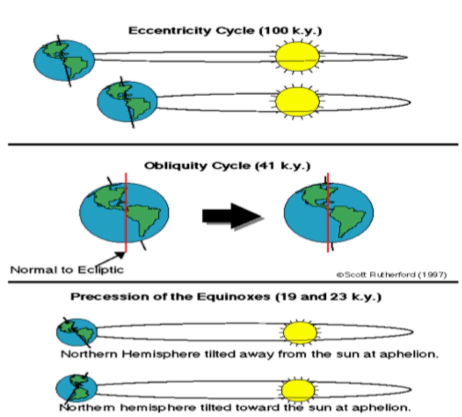

FIGURE 19
Powerpoint Slide: Milankovitch Cycles 2.

Jeff accurately communicated the facts printed on the slide. In his effort to give context so the students could understand the forces that drive Milankovitch cycles, and how the

[27] Scheffer (2009) argued that internal dynamics within the climate system drove the alternation between glacial and interglacial periods during the Pleistocene. In this conception, changes in Northern hemisphere summer insolation triggered state shifts that were already primed to happen. If so, then the development of a snowball Earth given the current placement of the continents would be much less likely than might be guessed by simple extrapolation.

cycles impact the climate, he made a number of statements which might make intuitive sense to a layperson, but which most experts in Milankovitch cycles would consider misconceptions. Most of these were even subtler than the one I described above.

The image on the slide was a key resource Jeff used in teaching about the Milankovitch cycles, and it may have been important for his self-education. During an interview, Jeff told me that he hasn't received a lot of formal education on climate change and conducts “independent research” in preparing his lessons. When I asked him what sources he uses, he said, “I'll do a lot of image searches, looking for certain things, that I know are pertinent to the conversation”. When I did a google image search on “Milankovitch cycles”, the image in Jeff's powerpoint showed up in the second position.

Many K-12 science teachers may not have studied Milankovitch cycles in college, and the texts that might help readers arrive at a deep understanding are often written for specialists. It may be worthwhile for experts to develop materials on the topic for use in high school classrooms and in teacher education programs.

Short Term Changes

Jeff went on to discuss on short-term changes, including the solar cycle and volcanic eruptions. The final two slides discussed the role of the oceans in regulating the climate; much of this reviewed material from earlier classes.

Other Issues

Several points did not easily fit into the description of what and how Jeff taught about climate change. In this section, we will look at the last three research questions in greater depth.

Resources.

As in David's case, Jeff's own skill, knowledge, and personality are his most important resources as a teacher. In particular, his personality influenced the unit itself, and may have influenced how he used other resources he encountered.

Drive for continual improvement.

"I keep testing the waters as to what is it I want them to do."

One of Jeff's greatest resources was his personal drive to improve his teaching practices. As the unit was ending, he spoke of his ongoing refinement of his approach to global warming.

> I keep testing the waters as to what is it I want them to do. Do I want them to just kind of synthesize, what do we know about global warming? Do I want them to try to pick a side? Do I want them to try to think about, what does a student in [this school] have to do with global warming? So, there are all of these different vantage points to get at the whole topic of it. [I keep trying to find] the best way to present, tackle, address, the idea of global warming.

Fair mindedness.

"If I were to present only one side, then I don't think I'd be doing justice either way."

Jeff is largely self-educated on the topic of climate change, and he said he relies on the media and his textbook as his main sources of information. He is aware that there is a lot of slanted coverage of the topic, and he therefore seeks information from both liberal and conservative media outlets.

> I’ve learned about climate change from watching TV. You [see] articles about “The Ice is melting” those kinds of events. [The media constantly brings] up the idea of global warming. […] And I also listen to talk radio, and some of the stations I listen to have a little bit more of a conservative slant, and so I get their data as well. […] So I don’t feel like the information I get is one-sided.

This is reflected in how he presents the information to his students, "I basically tell them that I want them to find information that’s on both sides of the argument. Because if I were to present only one side, then I don’t think I’d be doing justice either way”.

This might be troubling for someone who has studied the science in depth and recognizes that the scientific community has arrived at consensus on many key issues related to climate science. Any student who wanted to understand the current scientific debate would first need to understand the consensus. As I will discuss later, Jeff is deeply embedded in his school community, and it seems possible that if he slanted strongly towards the scientific consensus, it might not be well received by his students or their parents.

Local Universities.

"It wasn’t a brow beat […]."

Jeff and I met at a summer workshop on teaching about climate change. More than a dozen activities were presented at the workshop, but Jeff didn't use any of them in the classes I observed. When we discussed the workshop, he didn't state an intention to use any of them in the future. In fact, he hinted that the presenters might have been a little biased in emphasizing humanity's role in climate change, “It wasn’t a brow beat like, ‘Hey, we’ve got to get out there and tell the world’, but it was kind of, ‘Humans are part of the system and we’re affecting the system’.”

Later in the same interview, I asked him how the University of Georgia could support his efforts to teach climate change, his first response was:

> You can make a video [describing both sides of the debate]. (Laughs) […] The folks that feel that climate change is not influenced by humans whatsoever, what is the data that they’re using? […] How is [the same data] being used by those that are proponents of human influence on climate change? […] How can they take the same data and make it mean different things? […] And so I guess it would be nice to know if the data that we have–the patterns that exist because of that data–what does it suggest? […] Now, who is to say what comes from the University of Georgia is going to be any better or any worse than [anything else]? But that would be helpful for me.

From my subjective position as a science fan, I think it is very important for high school students to understand the scientific consensus on scientific issues, including climate change. But many teachers and students, including Jeff, may perceive the consensus as biased, which may lead them to discount presentations that focus on the scientific consensus. Jeff is trying to make sense of the debate for himself, and if the academic community only presents the scientific consensus, Jeff may not use the resources provided.

Institutional Factors

A number of institutional factors influenced Jeff's decisions on what and how to teach about climate change. I already discussed the how the large class size and finite electrical resources impacted the lab.

Time

"[T]here's a cumulative effect […]."

Jeff's oceanography course was taught in a single semester on a block schedule. Several factors conspired to reduce the number of class meetings. As he told me:

> Having the class in the morning, that's typically when we have most of our interruptions. Any kind of standardized testing has to be done in the morning, so that interrupts class time: and fire drills, and pep rallies and I guess there's a cumulative effect of all of that. […] By the end of the semester you've been shorted five or six days which in a block schedule is a unit sometimes.

Standards and End of Course Tests (EOCT).

"The main reason why some of the students take this class is for the marine biology part of it."

There is no EOCT in Oceanography, so Jeff felt at liberty to decide how much time to devote to each standard:

> Spending five weeks talking about the oceans and the atmosphere is not really doing the students justice when it's a course that doesn't have any EOCT. It has standards; I can address every one of those standards. It's just a matter of where do I want to spend most of the time, and where would the kids like to spend most of the time.

In the future, he may spend less time on topics related to climate change, to create more time to cover other topics:

> I felt like the [climate change] unit was taking a little bit longer than I wanted it to. […] I use so much of the teaching time [on] ocean currents and waves and temperature and chemistry. The main reason why some of the students take this class is for the marine biology part of it, so I don't want to short change that experience.

Socio-cultural factors

Having worked for 23 years in the same school, Jeff is deeply embedded within the school community. The school maintains high expectations, and over the years, Jeff has developed strong bonds with his colleagues in the science department. The local community is politically conservative, and this provides an important context for understanding how Jeff teaches about climate change

High achieving school.

"[T]he parents are highly involved, highly engaged."

Even before our first interview, I was struck by how clearly the school communicated the expectation that the students would go to college. Many of the bulletin boards contained information about colleges, and all of the classroom doors were decorated with handmade pennants showing the teachers' alma maters. When I asked Jeff how he would describe the school to someone who had never seen it, the first words out of his mouth were:

> This is a very high-achieving school. […] There's hardly any transiency. I would say that the students that I start the semester with, 99% of them are still here at the end of the semester. [...] We are predominantly Caucasian, approximately 93% Caucasian. So we are not a very diverse school in that capacity. Probably a middle-income level, so socio-economically, we have access to resources, and the parents are highly involved, highly engaged.

Colleagues in science department.

"I'm very proud of the department I work with."

According to Jeff, he and his colleagues in the science department have "developed some really strong bonds". Speaking as department chair, he told me, "I'm very proud of the department I work with". I met Jeff and his colleague Annette at a summer workshop on teaching about climate change, and Jeff described this as part of the department culture:

> Every year, and it may not be the same person, but every year, there's somebody that has gone to some kind of training, and they bring it back and they share it with us. […] We're very active in terms of continuing our professional learning.

Despite their closeness and presumably a shared interest in science, it seems that Jeff and his colleagues in the science department rarely talk about climate change. When I asked Jeff if he felt his colleagues supported his decisions on how to teach about climate change, he spoke about Annette with whom he attended the summer workshop:

> The only person that really talks about it with me much is [Annette] […] Now, I'm not sure exactly what she does with it. […] We haven't really compared notes. Actually, if I had to nail it down from her, what would she say? […] I don't know because I don't know how she feels about it. But I think we are the only two that have really discussed it much.

Politically conservative community.

> *"I haven't had a big push back, because I just let it rest with them."*

Jeff's school community is politically conservative:

> [Our school's] clientele tends to lean more towards a conservative viewpoint on a lot of things, and so climate change tends to be more something that liberals tend to [tak about]. So I feel like it's an important concept [for my students] to delve in and really look at data versus what their parents have told them.

When I asked Jeff if he felt his students' parents supported his decisions about how to teach climate change, he said:

> If I had [my students] pick a side, and then if we had talked about it in class, and if their position had been incorrect, and they'd gone home and said, "Well, that's not what Dr. [Zale] said about climate change." Then I

> might have heard back from them. […] I haven't had a big push back, because I just let it rest with them.

I highly doubt that Jeff presents both sides of the climate debate in order to avoid conflict with the school's "clientele". By encouraging his students to think through the issues for themselves, he is encouraging open-mindedness within a community that otherwise might not be open to discussing climate change in depth.

Case Summary

Dr. Zale is a particularly interesting case because his strong drive to improve his teaching, his service in a politically conservative community, and his efforts to make sense of conflicting media messages about climate change. Two classes that I observed centered on a lab activity that encouraged students to think through the complex issues that might emerge if the arctic sea ice were to completely melt. In discussing the lab with class, he focused on the complexities of the climate system, and the many ways the ocean might act to stabilize the climate. At the same time, he ignored the fairly simple (though politically charged) question of whether arctic sea ice has undergone significant reduction in either volume or extent in recent decades.

Jeff has mainly learned about climate change from a mixture of liberal and conservative media outlets. He stated that this allows him to get information from "both sides". He has supplemented this with his own internet research and by referring to the textbooks he uses to teach Oceanography and Meteorology. Although he participated in a two-day summer workshop on teaching about climate change, he did not make use of the resources presented at the workshop in preparing for the lessons in his oceanography class, though it seems possible he will use them in his meteorology class.

He looked at the standards in developing his lesson plans, but he felt that he had flexibility in determining what aspects of the standards to emphasize, especially given that there is no EOCT in Oceanography. In future years, he said he may spend less time on physical oceanography, including climate change, so he can spend more time on marine biology. He felt that the standards' explicit mention of global warming "pigeon-holed" him. Accordingly, he may change the "Global Warming One-Pager" into a "Climate Change One-Pager" thus allowing his students to discuss either global warming or global cooling in future years.

He voiced a high level of respect for his colleagues, and indicated that they have a strong social and collegial bond. Still they rarely talk about climate change, and he is the only oceanography and meteorology teacher at his school, so they were not an important resource in developing his lesson plans or deepening his understanding of the science.

The polarized debate in American society over the validity of climate science leaves Jeff searching for a trustworthy source of unbiased information about the topic. His efforts to present a balanced picture of climate science are well received in his politically conservative community, and he says that he has never heard a complaint from students, parents, colleagues, or administrators. He expressed hope that the University of Georgia might be able to provide unbiased resources for teachers.

Jeff is an exemplary case for his commitment to continual improvement as a teacher and his efforts to present a nuanced picture of a politically charged scientific topic. Annette Brown, whom we will turn to next, is exemplary for her commitment to gaining greater content mastery.

Case Three: Ms. Annette Brown – Lifelong Learning

"I learn something every time that I teach this."

Annette Brown teaches Biology, Environmental Science, and AP Environmental Science (APES) at the same large suburban high school as Dr. Jeff Zale, her Department Chair. My study of Ms. Brown's case prompts me to make assertions relevant to each of the research questions.

Research Question One (RQ1): What do teachers teach about climate change?

a) Annette teaches that climate change is one of many ways that humans are impacting the environment.

b) She includes explicit discussion of feedbacks in her class.

c) She says she teaches about legal issues related to climate change.

d) She told her students that Metro Atlanta's climate had changed in her lifetime.

RQ2: How do teachers teach about climate change?

a) Annette uses a range of teaching modalities including lecture, group work, labs, and computer work.

b) She asks the students to take responsibility for their own learning.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) Annette's most valuable resources are her own skill, knowledge, and personality.

b) Her commitment to learning the content she is responsible for teaching is so deep that it constitutes an aspect of her personality. In expressing her personality, she models lifelong learning for her students.

c) She draws on a large number of resources for her teaching and to further her own education. This resourcefulness may constitute an aspect of her personality.

d) She offered several suggestions for how the University of Georgia might support K-12 climate change education in Georgia.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) Annette refers to both AP and Climate Literacy standards when developing her lessons.

b) The support of her department chair enabled her to attend a workshop about climate change education that influenced her teaching.

c) Time constraints limit how much class time Annette devotes to climate change, so she asks her students to take responsibility for their own learning outside of class.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) Annette reports that in previous years, several students have questioned the scientific consensus during class, and this prompted her to change her instructional approach.

Synopsis

I observed Annette as she taught a unit on climate change that consisted of three ninety-minute lessons that were part of a unit on air pollution within an AP

Environmental Science (APES) class. I was present for two of the lessons, but I was observing another teacher during the third. Annette accommodated me by videotaping parts of the lesson I missed, and this enabled me to glean enough information to inform my research questions

Annette is an exemplary teacher in many ways: Most obviously she provides her students with a model for lifelong learning. As she told her class, "I learn something every time that I teach this".

Day One: Air Pollution and Online Activity

When I entered Annette Brown's classroom for my first observation, Annette was sitting behind a desk that was covered with books and papers and nestled between two file cabinets and a bookshelf. She was staring intently at her computer, and her fingers danced over the keyboard. She greeted me politely, explained that she had work to finish before class, and invited me to set myself up wherever I felt comfortable. While Annette's desk was cluttered, her room was extremely tidy. The lab counters lining the back wall were almost completely empty and provided a clear view of the bank of white boards and screen that I guessed Annette would use in her lessons, so I set myself up there.

Thirty-three students (an even mix of boys and girls, 30 seemed European American, two seemed African American, and one seemed South Asian) entered the room and seated themselves in groups of three, four, or five spread out among nine pairs of black lab tables. Each group had a large sheet of poster paper rolled up in the center of their desks, and any student who looked at the whiteboard would have seen the day's agenda written in large black letters.

1) Review: Air Molecules, Biogeochemical Cycles.

2) Carbon Cycle Lab Discussion

Review: Air molecules.

"Why is [carbon dioxide] not [considered] a criteria pollutant?"

Annette started class with a review of atmospheric chemistry that made use of a collection of 'Air Molecules Cards' (See Appendix E1) that each student had cut out and colored following a uniform color scheme. Annette asked questions like, "Which naturally occurring gas is very common today, but was not part of the atmosphere early in the Earth's history?" The students would all indicate their answers by holding up one (or more) of the cards. This allowed Annette to quickly see which students had mastered the material, while also providing an opportunity for review. Early in the review, Annette asked, "Which gas do plants use for photosynthesis?" After the students indicated their answers, she said:

> Carbon dioxide. We've already talked about carbon dioxide and how it links to photosynthesis and respiration. Today, we're going to look at some other sources of carbon dioxide. We're going to look at some anthropogenic–some manmade, some human–sources of carbon dioxide.

When she was done discussing carbon dioxide, she reviewed "other pollutants".

Annette was the only teacher I heard refer to carbon dioxide as a "pollutant", and she did so quite casually. The question of whether to consider carbon dioxide a pollutant is central to the legal struggle over climate change in the United States. In 2009, 350.org and the Center for Biological Diversity petitioned the EPA to add seven greenhouse gases to the list of six “criteria air pollutants” that receive extra scrutiny under the Clean Air Act, and called for setting acceptable levels of CO_2 at 350 ppm–or about 50 ppm below current levels (Center for Biological Diversity, 2009). Even within the environmental movement, calls for regulations to reduce current *levels* of atmospheric carbon dioxide are considered radical.[28] Most environmental organizations call for reducing the *emission rate*. Annette doesn't come across as radical. But in an interview, she clearly advocated regulating carbon dioxide as a criteria pollutant.

> Sometimes I want to ask the kids, “[…] Why is [carbon dioxide] not [considered] a criteria pollutant?” […] The United States says, “We can't do anything to monitor the amount. We can't make businesses–or we are not going to make corporations–limit themselves”.

Introducing greenhouse gases.

“[…] they are teaching me things everyday […].”

After reviewing primary and secondary pollutants, Annette asked the class to identify six greenhouse gases. The students worked independently for a minute, when a student sitting near me told the other students at his table, “I don't know”. Then he turned to me, and said, “Do you know?”

I laughed, and said, “I don't think I'm supposed to tell you”. But since the students had a set of pictures of air molecules in front of them, I added, “None of them are just

[28] In the case of Utility Air Regulatory Group v. Environmental Protection Agency (2014), the Supreme Court issued an opinion saying the EPA can regulate CO_2 emissions but it cannot apply the same standards as are applied to most pollutants, much less criteria air pollutants. Some media outlets reported that it was a 9-0 opinion, but that masks deep divisions. Scalia wrote for the court, and only two other justices signed on to his opinion. Two other opinions concurred in part and dissented in part, and majorities were thereby cobbled together for each part of the decision. Thus the claim that it was unanimous is as correct as the claim that six justices dissented. In fact it was a 4-3-2 opinion, with the four liberal justices on one extreme, and Alito and Thomas on the other.

single atoms or pairs of atoms. They all have at least three atoms, and at least two different kinds of atoms".

The student responded, "OK", but didn't seem to understand. This brief interaction planted a seed that Annette would harvest the next day.

After the students worked for two more minutes, Annette reviewed the names of the greenhouse gases, while holding up the appropriate Air Molecule Cards, as she mentioned each gas. Rather than telling the class about each gas, she told them that their readings would have more information. Annette was relying on the students to study a lot of material on their own, and they were expected to keep notes about each gas on their Air Molecule Cards.

The cards were an important resource for this section of the class. Annette had "never done them until this semester". She learned about them "from a friend who teaches at another school". The cards are useful for more than formative assessment and review. They made it easy for her students to access the information they gleaned from their research, which in turn helped Annette to learn from her students. As she explained in an interview, "They have air molecule cards, […] and they have to write notes on the back. So, they are teaching me things everyday, because they have a lot of information on those cards".

Review: Biogeochemical cycles.

"I want them to understand that it all starts with how many people there are."

Annette announced that the students would have ten minutes to work on posters they had been making as they progressed through the course. The students unrolled the large sheets of paper on their desks, and I could see that they had drawn landscapes with mountains, rivers, a desert, an ocean, and a factory. Annette demonstrated how to draw three clouds representing primary pollutants, secondary pollutants, and greenhouse gases, and instructed the students to fill in the appropriate pollutants in each cloud.

I am asserting that Annette teaches that climate change is one of many ways that humans impact the environment. The students had started the posters before their climate change unit, and they will continue to work on them as the course continues. By including greenhouse gases as one of three air pollutants on the poster, she was integrating climate change into the larger field of environmental science. In discussing the course as a whole, she said, "I want them to understand that it all starts with how many people there are. […] We've been emphasizing pollution all along, and we started [by discussing] human population".

Activities on the carbon cycle.

"The course I took this summer has influenced me a lot, because we saw new resources."

The final hour of the class was devoted to two activities Annette had learned about at the two-day summer workshop on teaching about climate change where we met. She started by showing a Prezi about the carbon cycle that was developed by one of the workshop instructors (Diem, 2013). The Prezi talked about "the carbon crisis" and one of the films embedded within it described fossil fuels as "problematic" and "unsustainable". Annette accepted these characterizations as if they were simple statements of fact.

At the end of the Prezi, she announced that the class would be going to the school's media center to work in pairs on an online lab, which she had also adopted from the summer workshop. The activity asked the students to read a webpage (Riebeek & Simmon, 2011), and complete a handout with several questions related to the webpage (See Appendix E2). The media center was spacious and comfortable with about twenty computers. Three librarians were on staff, and one of them helped with technical problems that arose, so Annette was able to focus on helping students understand the material on the website. In addition to the website, and the materials Annette had gathered from the workshop, the school's infrastructure was an essential resource for this part of the lesson.

I am asserting that Annette draws on a large number of resources to further her own education and that of her students. In discussing the summer workshop where she encountered both the Prezi and the online lab, Annette told me, "I really loved that we got to see all the [resources the professors] had developed for [their college] course", and the workshop "influenced me a lot".

Interlude- Recruiting an unsuspecting resource.

"OK, awesome. Yes, please, please share."

During an interview later that day, Annette mentioned that a lot of students confused stratospheric and tropospheric ozone. I probed and asked her what other misconceptions she encountered. She answered, "I'm drawing a blank at the moment".

I suggested, "A typical one is that as sea ice melts, sea levels rise".

"Yeah. That's true", she responded.

“It’s like ice in a glass. It’s floating in the water, so it’s already raising the level”.

“Oh, I got you. Okay. Sea ice, okay. […] Then that’s just the difference between sea ice, and …” she paused.

“… glacial ice”, I said.

“Okay, I got you. I see what you're saying”.

Later in the same interview, I briefly mentioned the short exchange I had with the student who wanted me to tell him which gases were greenhouse gases. She didn't seem to understand my brief explanation any better than the student did, so I promised her that we could talk about it after the interview (See Appendix E3). She responded, “OK, awesome. Yes, please, please share”.

I am asserting that Annette is deeply committed to learning the content she is responsible for teaching, and that she is highly resourceful. Each of the teachers I worked with brought out different aspects of my complex teacher subjectivity. Annette is so committed to her own learning that we sometimes interacted not as two teachers, but as teacher and learner.

Day Two: Review and Introducing Two Labs

I was observing another teacher during the second day of Annette's climate change unit, but she was able to videotape much of the class session for me, and this has provided enough information to inform my research questions. Annette started the class by reviewing the day's agenda which was posted on a powerpoint slide:

1) Review GHG [Greenhouse Gas] Molecules.

2) Review Notes: Weather, climate, and global climate change.

3) Outdoor Labs: Albedo and Greenhouse Effect

Even though I was not in the room, at points while watching the video, I felt that I was present, because a number of issues that had come up in our interview the day before were included in her lesson.

Review and elaboration.

"This was like an aha for me."

Annette started the review of greenhouse gas molecules by asking the students to tell her which of the air molecules were and were not greenhouse gases. As the students called out their answers, she listed them on the whiteboard. Then she asked, "What determines whether something is a greenhouse gas?"

The students did not answer, so she said:

> They trap heat. […] If we look in the electromagnetic spectrum, heat is in the infrared. So these gases can actually absorb infrared. They absorb heat. So that's the main reason they're greenhouse gases.

Then turning to the class, she asked, "If you look at these molecules, do you see something that's the same about all of their [structures]?"

The class was silent.

She continued:

> If you look at the shapes of the molecules, they're not linear[29], and they're usually three or more atoms. So because of the shapes of these molecules, they're able to absorb that energy, and trap that infrared heat, and oscillate in a particular way, within their molecular structure.

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[29] Readers who are versed in atmospheric science will notice several misstatements. I will not point them out. I am asserting that Annette is committed to learning the content she is responsible for teaching, not that she has already achieved expertise.

I wasn't present in the room, and the video camera was focused on Annette, so I couldn't gauge the class's reaction, but she later told me, “I have a few [students] in AP chemistry, and their eyes lit up when I [talked about the structure of greenhouse gases], like ‘Oh, this sounds like chemistry.’ So that was really good for them too”.

Then she talked about methane and focused on permafrost. She defined permafrost as:

> [Places] where the ice is frozen most of the year, [but] as it begins to thaw […], there are places where bacteria decompose organic matter […] and we get production of methane from those places. […] So the issue with permafrost melting isn't production of water, it's production of methane.

She used the example of melting permafrost to discuss “positive and negative feedback loops”.   She went through the steps of the feedback on the white board, and concluded by saying, “increased warming, increased melting, increased methane, increased warming” as her hands traced a circle in the air. “OK, that is a positive feedback loop. […] A positive feedback loop is like a vicious cycle”.

Watching this, I realized that once again, I had become a resource for her teaching. (Or more accurately, I had become a conduit that allowed her to access David Woolf’s skill and knowledge.) In response to a question I had asked in the prior day’s interview, Annette told me that, “[my students] don't understand positive […] and negative feedback. […] They think that positive feedback should be something positive in the sense of […] a positive outcome. […] The wording is terrible”.

I responded, “Yeah. […] One teacher I saw avoided the words; […] he talked about vicious cycles”.

Having described positive feedbacks as vicious cycles, she displayed a slide with a picture of sea ice, and asked, “If that ice melts, will sea levels rise?”

Several students responded, and one student confidently called out “No”.

Annette agreed, “And here’s the misconception. Sea level will not rise from this”.

The confident student called out, “It will be the glaciers melting”.

“Yes, it will be the glaciers melting. Because the glaciers are on land, they’re not in the water”.

“So they’re not displacing the water”. It was the same student.

“So they’re not displacing the water”, Annette repeated. Then turning to another student she said, “Ahh, you're figuring this out. This was like an aha for me. So I had to do my reading once again. I learn something every time that I teach this”.

I am asserting that Annette models lifelong learning for her students. In this exchange, she spoke about the joy of learning by describing the moment of understanding as an “aha moment” while also acknowledging that learning requires work, by saying that she followed up the “aha” by re-reading material she had already read.

Climate change comes home.

“I planted daffodils.”

After showing a brief animation about the ice-albedo feedback, Annette asked the class:

> Have you guys talked to your parents about whether bloom times have changed since they were kids? […] We've lived here for 20 years […]. I planted daffodils […] the very first year we moved here, and my

> daughter's birthday is [in early March], and we always say that on [her birthday the daffodils] are in full bloom. […] As we've lived here, spring has changed a little bit, and my daffodils now are in full bloom about a week before her birthday.

The day before the class, when she told me about her daffodils, I thought to myself that Annette was expressing a misconception, that she was not seeing climate change, but she was experiencing Atlanta's urban heat archipelago (Rosenzweig et al., 2005).

Ironically, Annette was aware of the urban heat island effect, but did not seem to realize that it reached into her own backyard (see Figure 20). Immediately after talking about her daffodils, she discussed how climate can be local, regional, or global, and mentioned that in Atlanta, there is "an urban heat island effect, [and] Atlanta is around three to five degrees warmer than us all the time". As I watched the class on videotape, I realized that Annette wasn't so much expressing a misconception as stating facts. Her daffodils are blooming earlier, and Metro Atlanta's climate is changing.

This elaborates on my assertion that Annette's skill, knowledge and personality are important resources for her teaching. Annette's interest in gardening helps her understand how climate change is impacting her life, and allows her to communicate that understanding to her students. Some scientists might say that she is communicating a misconception–that she is confusing local and global climate change. But the climate in her backyard has most likely changed in the last twenty years. This makes the fact of climate change real to her, and possibly to her students. Given the impact of land cover changes on both global, regional, and local climate and the importance of the urban and suburban environments for human populations (Mahmood et al., 2014; Seto & Shepherd, 2009; Shepherd et al., 2013), Annette may appreciate the essential issues better than many climate scientists.

FIGURE 20
Metro Atlanta's urban heat archipelago as recorded on September 28, 2000. Top image shows Atlanta and some of its suburbs in true color. Bottom image is a land surface temperature map based on infrared imaging. Note that many of the small islands within the archipelago are as hot as the main island (Atlanta).[30]

Day Three: Review and Lab

"They're all related in some ways."

The last of Annette's three classes on climate change focused on review and an outdoor lab activity. Annette started class by giving the students an activity to review

[30] Public domain image by Marit Jentoft-Nilsen; reprinted in Przyborski, 2008.

global warming (Molnar, 2005, pp. 209-211). After doing a short reading, the students used sticky notes to organize a concept map that related global warming and other environmental challenges to decreases in agricultural production. As the students worked in small groups, Annette visited each of the tables, and coached them on the assignment. Many groups made the same mistake. After noticing it on one group's sheet, she asked, “Is Acid rain caused by greenhouse warming?”

A student answered, “I don't know. Maybe it goes here”, and moved the sticky note to indicate that acid rain is caused by deforestation.

Annette then asked, “Are they related? Is acid rain tied to […] deforestation?”

“Yeah”, answered the student.

“Are you positive? Deforestation causes acid rain? How are they related?”

Another student spoke up, “The chemicals get in the air from burning coal, so it’s related to global warming”.

“Well, acid rain comes from coal, but is it caused by global warming? Think of it this way: Acid rain is a secondary pollutant”.

Another student spoke up, “So it’s not connected”.

Pointing to one of the circles on the handout (Molnar, 2005, p. 211), Annette said, “So look at this one. It’s out here [by itself]. So if acid rain goes here, does it cause decreased agricultural production?”

“Yeah”, answered a student.

“So I’d leave it there”. Then moving another sticky note, Annette said, “Same with ozone depletion. So these are kind of independent. Yes, they’re all related in some ways, but [global warming and deforestation don't cause acid rain]”.

In discussing Annette's statements about her daffodils, I hinted at my own dual subjectivity. As a science fan, I considered her belief that global climate change was related to her backyard phrenology to be a misconception; as a layperson, I felt she might understand the essential issues better than most climate scientists. Now, Annette's subjectivity as a scientist was coming out, and she was emphasizing the distinction between global warming and acid rain, and between primary pollutants (like carbon dioxide) and secondary pollutants (like sulphuric acid). Her students were speaking from a lay subjectivity that sees the intimate connections between acid rain and global warming and between primary and secondary pollutants. In her role as a teacher, Annette needs to prepare her students for the AP exam, but I found myself wondering whether these distinctions are crucial for understanding the essential issues.

The students gathered their supplies, and we went outside to conduct two lab activities. The first investigated the concept of albedo. The students needed to take the temperatures a few inches above the ground over ten substrates, including asphalt, concrete, and several of their own choosing. The second lab involved placing thermometers into two plastic cups, covering one of the cups with clear plastic wrap, placing both cups in the sun, and taking the temperatures in each cup at five-minute intervals. The students had been outside to attempt the lab a few days earlier, and they got to work without any instruction from Annette. The overall mood was very relaxed. Annette spent her time developing her rapport with her students by engaging in casual conversation. Her easy manner with the class represented an aspect of her personality. It seemed to contrast with the way she presented herself to me in private, where she sometimes seemed stressed by the need to cover a lot of material in a short amount of time. I will return to this issue in the next section, when discussing sociocultural issues.

Other Issues

In discussing what and how Annette taught about climate change in the lessons I observed, I have touched on other research questions. I have talked about the many resources that she used in developing her lessons and in learning about climate change; I have also discussed how time constraints, her need to prepare her students for the AP exam, and the climate literacy standards impact her instruction. Some of my assertions don't easily fit into a description of her teaching, and I will address them now.

What she teaches in other units.

"We will talk about the Kyoto protocol in here."

Climate change connects with the Environmental Science curriculum at many points. Annette mentioned that early in the term, the class studied nutrient cycles including the carbon cycle, and that her students "made the connection to what we had done before". Although I didn't see her discussing legal issues in class, she said she integrates Environmental Law into her curriculum, and connects her curriculum to what the students are learning in Government class.

> It's different with different groups of kids. It depends sometimes on the teacher in the Government class and what they're doing. […] We will talk about the Kyoto protocol in here, and they will talk about that in Government for sure. Montreal protocol: They don't always talk a whole lot about, but we talk about it here.

Earlier in the term, the class had done an in-depth study of the Clean Water Act, and Annette said her students learned a lot from it. She said, “We could do the exact same thing with the Clean Air Act, […] it just takes time”.

Resources.

“I’m assuming you’re going to go with me.”

As with the other teachers in this study, Annette’s own skill, knowledge and personality are valuable resources, which in turn enable her to access other resources. In discussing her lesson plans I have focused on the books and workshops she used, but she is also very skilled at recruiting people to help her. I have already discussed how she recruited my assistance in helping her learn the chemistry and optics of greenhouse gases as well as the distinction between glacial and sea ice. She also made it clear to her students that they needed to take responsibility for studying outside of class, and asked them to share what they learn with each other, thereby recruiting their assistance in both of her roles as teacher and learner. She also recruited her department chair (Dr. Zale) to accompany her to the workshop on climate change where I met both of them.

> Last summer, when [Jeff told me about the two-day workshop], I said, “Please sign me up, because I really need to go”. [Later] I sent him an email and said, “Did you sign up for this? I’m assuming you’re going to go with me”. […] And he goes, “Oh, I forgot, thank you”.

No doubt, she recruited Jeff to attend the workshop largely because she believed that he would benefit from it. But I’m sure she also enjoyed his company, and discussing the workshop with Jeff may have helped reinforce her learning.

Speaking subjectively: Of all the participants in this study, I found Annette the most endearing. She was very open about the challenges she faces in teaching a subject (Environmental Science) for which she has little training, and this made me want to help her. I suspect she is highly skilled at recruiting people to help her learn.

Annette had several recommendations for how the University of Georgia could better support K-12 climate change education. The first was to develop a website for K-12 educators that would present "evidence for climate change around Georgia". The site could include phenological data, like "bloom times for plants and flowers" as well as "rainfall data" and "data [about] greenhouse gas emissions". She explained, "It would not have to be really involved", because "[the students] could create their own graphs from that data". She also said that, like her, many Environmental Science teachers are trained in biology, and lack some of the needed content knowledge, especially in meteorology. She perceived a real demand for a summer workshop that would provide a crash course, perhaps four days long, on meteorology: "Everybody says the exact same thing".

Institutional factors: Standards and time.

"Wait a minute, I am covering it."

The rigorous demands of the AP exam and Annette's commitment to the Climate Literacy Standards require that Annette use class time wisely. I am asserting that Annette asks her students to take responsibility for their own learning, and that she is constrained in how much class time she can devote to climate change. Annette's interpersonal skills include skill at encouraging her students to take responsibility for their own learning. In discussing the rigors of the AP exam and the Climate Literacy Standards, she told me:

> I felt like I couldn't possibly cover all of this, but then I realized, "Wait a minute, I am covering it". [I tell my students they have] to work outside of class. Otherwise they'll miss major parts […] just because of time.

Earlier, I mentioned that while they were doing their lab, Annette spent more time chatting with her students than she did supervising their work. I have found that the teacher-student relationship can be highly motivating for many students. By taking the time to build rapport with her students, Annette may have helped encourage them take on greater responsibility for success in her class.

Institutional factors: Administration.

"They seem extremely busy and overworked."

Annette says her administration is "supportive, but […] they seem extremely busy and overworked". The issue became more acute months before my observations.

> We lost [an administrator] due to budget cuts, so they had to take those responsibilities and divide them up among the four remaining people. […] [So] they ask us to take on certain responsibilities and take on more things.

When I approached Annette's principal requesting permission to do this project, he originally balked, and voiced concern about how his politically conservative constituents might react to their children learning about climate change. Given the principal's reaction, the school's large size, and the cuts in administrative staff, it seems possible that the principal and others in the administrative offices are not deeply aware of what is happening in Annette's classroom.

As science department chair, Jeff may have the main responsibility for supporting and overseeing the science teaching staff, and he is clearly supportive of her efforts to teach climate change. When he learned about a workshop on teaching about climate change, he forwarded the information to Annette, and when she suggested he attend with her, he did so.

Sociocultural Factors: Homogeneity.

"They can be too silly with one another."

According to Annette, "As far as socioeconomic class, [this school is] almost homogeneous, in that we're upper middle to upper class [and] mostly white". Annette found the uniformity to be a challenge.

> Other places that I've taught were more diverse, much more diverse. You had more of a span of races. […] So, sometimes […] the way they treat one another in the classroom can be different, because those kids that were from a more diverse background I found much more respectful to one another in the classroom […]. These kids walk into the room, and it's like, "Oh, he's just like me" or "Oh, she's just like me". So sometimes they don't respect each other. […] They can be too silly with one another.

In my subjectivity as a teacher, I never sensed a lack of "respect"; nor would I have used the word "silly". But the room felt relaxed, and some of the students seemed more focused on social interactions than on learning. I'm sure Annette adjusted her practice to the school's sociocultural environment. Her manner in class was relaxed. From our discussions outside of class, I knew that she can also be very intense and focused on her job. I suspect she took on the more relaxed persona to relate better with her students, which may in turn have aided in her efforts to encourage them to take responsibility for their learning.

Sociocultural Factors: Political and Social Controversy.

"There is enough bad information out there without you adding to it."

Annette told me that this year's class supported her decisions about how to teach climate change, but that in this past, she faced some opposition. She used to have her students do independent research in groups, and then they would come together and have a "Socratic seminar" in which they would discuss what they learned.

> I [felt] like they didn't get very much background, and sometimes they didn't actually find some of the information that they needed to really know. […] They'd find material that wasn't correct, and then sometimes they [would] make things up. [And I would think], "You don't want to make things up; there is enough bad information out there without you adding to it". […] I've learned […] that I need to be more direct with this, because there is so much information out there and even the information that I give them is a lot for them to read and process.

So Annette decided against having her students do independent research, because in previous years, the social and political controversy had reached into her classroom and prevented her students from learning the scientific consensus.

Annette told me that she never had a parent question her decisions about how to teach climate change. Still, she was sure that many would say, "I don't believe in it anyway". But this didn't seem a major concern for her, "You know, parents".

Case Summary

"[…] by 2020 these guys will be out making a change in the world."

Annette is an exemplary case because of her deep commitment to teaching and learning. She lacks formal training in Environmental Science, and finds the rigors of the AP curriculum challenging. Still, she is extremely resourceful and is working hard to meet the challenge. She uses a variety of resources in developing her lessons, and found a two-day summer workshop on teaching about climate change to be especially helpful. She presents the scientific consensus on climate change without any hint that it might be controversial, and she told me that she devotes class time to discussing legal and governance issues related to climate change. Although her persona is quite moderate, she expressed a stance on the regulation of carbon dioxide that is radical even by the standards of the environmental movement, and stated that climate change was unfolding in her backyard. She asked her students to take responsibility for their own learning, in preparation or even greater responsibility in the future.

> I want them to be able to analyze it for themselves, because [my students are] going to [make] a difference. Because it's 2013; […] in 2017, these guys will be graduating college; and by 2020 these guys will be out making a change in the world.

Case Four: Mr. Thomas Butler – Problem Based Learning (PBL)

"Awesome."

Thomas Butler teaches 6th grade Earth science at an International Baccalaureate (IB) school that serves around 700 students a few miles from downtown Atlanta. Tom's commitment to geoscience education goes beyond his work as a teacher. During his thirteen-year teaching career, he has twice travelled to Greenland to participate in climate change research, and he stays up-to-date with the news about climate change. My study of Tom's case prompts me to make assertions relevant to each of the research questions.

Research Question One (RQ1): What do teachers teach about climate change?

a) Tom distinguished between global warming and climate change, and highlighted the role of greenhouse gases in climate change.

b) He taught that recent climate change is mainly driven by human actions.

c) He asked students to research geoengineering solutions to climate change.

RQ2: How do teachers teach about climate change?

a) Tom framed his instruction as a Problem Based Learning (PBL) unit.

b) He runs a student-centered classroom, and most of the class time was devoted to students doing independent and group work.

c) He created a safe and empowering learning environment.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) Tom's most valuable resources are his own skill, knowledge, and personality.

b) He habitually praised his students, and the habit seemed so deeply ingrained, it could be considered an aspect of his personality.

c) His experience doing climate research in Greenland and his continuing interest in the topic has given Tom a good understanding of climate science.

d) He provided his students with a number of internet-based learning resources.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) Tom was aware that the 6^{th} grade GPS don't mention climate change, but this didn't prevent him from covering the topic in depth.

b) His school's IB focus influenced his instructional decisions.

c) During most of my observations, Tom had two other teachers in the classroom. Their presence supported a student-centered approach.

d) Tom reported that his administration encourages teacher creativity.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) The classroom is an important sociocultural environment, and Tom encouraged his students to support each other's learning.

b) He reported that parents are very supportive of the school.

c) Tom reported that in previous years two parents have challenged him on his approach to teaching climate change, but he was able to work through these challenges.

Synopsis

I observed Tom teaching ten fifty-minute classes to each of two groups of students. The classes were framed as a PBL unit that culminated with the students evaluating a number of proposed geoengineering solutions to the problem of climate change. The first group of students was an inclusion class with twenty-three students, and the second was a regular class with twenty-two students. Both groups had an even mix of boys and girls; about 2/3 of the students in each group seemed to be European American, and the majority of the remaining students seemed to be African American. Tom gave the inclusion students a short bathroom break at the beginning of class, and several inclusion students had to leave early for Spanish. Although the inclusion class worked under tighter time constraints than the regular class, Tom's instruction was similar with the two groups. My description will focus on the inclusion class, and I will specifically mention the regular class when I note an interesting difference between the two.

During most of my observations, a special education teacher and an experienced private school teacher (who was doing her student teaching in pursuit of a public school certificate) were present in the classroom. Most of the class time was devoted to independent and group work, but the students had a lot of adult guidance in doing their work. Tom provided scaffolding by setting clear tasks for the students to perform each day and by giving the students resources to help them accomplish their tasks. Most of the class periods ended with time for students to share what they had learned, and during the sharing Tom would emphasize key points that he hoped the students had gleaned from the day’s activity.

Tom never mentioned it to me, and I saw no plaques in his classroom, but he has been named ‘Teacher of the Year’ for his district, and he was recently recognized as the ‘Outstanding Earth Science Teacher’ for the Southeastern region of the United States. He is an outstanding teacher in many ways: One of the most obvious was the amount of praise he lavished on his students. Words like "awesome" frequently passed his lips.

Day One: *The Day After Tomorrow*

"the hook"

Tom used the trailer and opening eight minutes of *The Day After Tomorrow* (Emmerich, 2004) to kick off his PBL on climate change. The movie is notorious for its misrepresentation of climate science, and Tom used his own skill and knowledge to judge how best to use the movie. Snyder (2007) said that the main purpose of the opening minutes of a movie is to "grab [viewers'] interest" (p. xviii), and trailers are designed to be attention grabbing and memorable. Tom used these exact segments as hooks to grab his student's interest, while introducing basic concepts about climate science that would be elaborated over the PBL.

Tom has been refining this PBL since 2005, when he and a colleague took a workshop at a local university on developing PBL cases. At the time, they were teaching 6th grade physical science, but they knew that in 2006, the GPS would change, and 6th graders would start studying Earth science. Accordingly they "developed some different cases [for physical science that could also be used in] Earth science". *The Day After Tomorrow* had been released about one year earlier, and Tom and his colleague decided to use it as "the hook to get into climate science".

> Clearly the intent wasn't to teach climate change from watching […] the movie. [I point out that] this is a [fictional] movie, [but there] are some of the true things in it–like Larson B Ice Shelf is a real place […]. [The

movie also introduced] some of the vocabulary that we'd be exploring [and] the idea of greenhouse gases somehow being responsible for [the collapse of the Larsen B Ice Shelf].

Tom's understanding of climate change, his instructional goals at the start of the unit, and his intuitions as to which segments would best capture student attention determined how he used the resource. The segments he chose contained no major scientific inaccuracies.

This first class session provides an opportunity to examine how Tom's personality and skill manifest in his teaching. So I will examine it in greater depth than later lessons.

Introducing the PBL

"Do you want to call on someone to help?"

Tom introduced the ten-session climate change unit by reminding students of their two previous PBLs. Then he turned their attention to the leftmost whiteboard where he sketched a 'Box Chart' (see Figure 21).

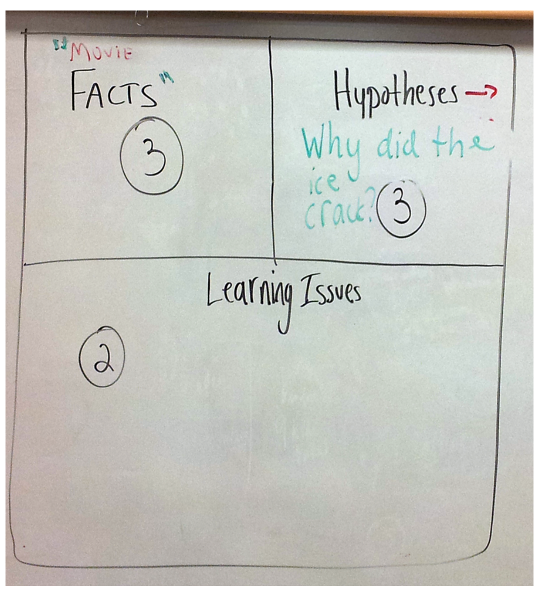

FIGURE 21
Model for student 'Box Charts'

He reminded them that in previous PBLs, they started filling in their Box Charts by looking for facts, but:

> This [time], we're going to look at movie facts. Because [we'll be watching] a science fiction movie, [and] we're going to try to figure out what is true, and what is misleading. After we watch the clip, you're going to write down some movie facts. Then you're going to write down some hypotheses.

Then he asked, "Who remembers what a hypothesis is?"

A couple of students raised their hands, and Tom called on one who said, "Uh, um, uh".

As the student hesitated, more hands went up. Tom ignored them, saying, "It's right on the tip of his tongue".

The student continued to hem and haw, and more hands went up.

Tom repeated, "It's right on the tip of his tongue". Then after a few more seconds, "Do you want to call on someone to help?"

One student called out, "Me, pick me", and the first student called on him.

The second student said, "An educated guess".

Tom responded, "Awesome, an educated guess, or an educated prediction".

The first student said, "I was about to say estimate".

"Awesome".

I am asserting that Tom created a safe and empowering learning environment. Many teachers might have dealt with the situation by asking, "Do you want me to call on someone else?" Tom started by encouraging the student, and when it seemed that the student did not have the words “right on the tip of his tongue”, Tom invited the student to use his power as the center of the class’s attention to call on the next person to speak. The difference between, “Do you want me to call on someone else?” and “Do you want to call on someone to help?” may seem subtle, but hundreds of these subtle actions helped create an environment in which Tom’s students were both safe and empowered.

Opening sequence from *The Day After Tomorrow.*

“[…] think about what could cause this ice to crack. And think about two learning issues–two things that you want to learn.”

Many teachers relax or attend to other tasks while showing movies, but Tom continued to pose questions and call on students as the credits rolled over images of icebergs floating in the ocean. Three minutes into the movie, Tom paused the DVD, with an image of an American flag and the words, “Larsen B Ice Shelf, Antarctica” projected on the screen.

He asked, “Where is this taking place in the movie?”

When a couple of students had trouble answering the question, he drew the class's attention to what was written on the screen, and a chorus of students called out, “Antarctica”.

“Antarctica. Where in Antarctica?”

Several students answered at once, “Larsen B Ice Shelf”.

At this point, he returned to the movie for the opening scene–a literal cliffhanger in which the hero almost died while collecting ice core samples, presumably during the

2002 collapse of the Larsen B Ice Shelf. At the end of the three-minute scene, Tom paused the DVD, and instructed the class:

> With the people at your table, you want to try to write down at least three movie facts: Where is this taking place, what are these people doing, what happened? Then for hypotheses, you want to try to come up with at least three different hypotheses for why the ice might be cracking. […] And think about two learning issues–two things that you want to learn.

As Tom spoke, the two other teachers handed out large sheets of paper and markers, and the students quickly started to work.

Working with small groups.

"When we say global warming, what are we talking about?"

I accompanied Tom as he walked around the room chatting with each of the groups while they worked. In these discussions, he rarely mentioned any of the 'Movie Facts' the students had written down, but often probed on their 'Hypotheses' and 'Learning Issues'. The students came up with many hypotheses for why the ice cracked, and Tom treated them all as equally valid. If a particular group didn't mention global warming, neither would Tom.

One typical exchange started with Tom approaching a group that hadn't recorded any of the three required hypotheses. After looking over their sheet, and listening quietly for a minute, Tom asked, "What do you think might have caused the ice to crack?"

One student answered, "Maybe the drill".

With Tom's encouragement, the students debated whether the drill could crack the ice, and Tom resolved the debate by urging them to write it down as one of their hypotheses, and asking, “So what else could cause the ice to crack?”

A student answered, “Global warming”.

“Global warming: What do you mean by that?” asked Tom.

“I don’t know”, said the student.

After some more discussion, Tom said, “So you can write global warming”. Then he probed again, “When we say global warming, what are we talking about?”

The students were quiet for a few seconds, and Tom changed the topic, “What else could cause the ice to crack?”

Silence.

Tom filled the silence, “It’s hard to come up with hypotheses, isn’t it?”

One student asked, “An earthquake?”

The group briefly discussed the earthquake hypothesis, and Tom left saying, “I like that. So I think you guys are good for hypotheses”.

Later Tom explained that he considered this part of the lesson to be an informal “pre-assessment”. This group was typical, and Tom concluded that his students “were […] coming in with a blank slate. They may have heard some stuff here and there, but [they] haven't really thought about [climate change] that much”.

In addition to accessing the student knowledge, during group work he often monitored group dynamics–intervening when necessary, but stepping back when things were going smoothly. As he told me while discussing a later class session:

> [I was] just looking around the room seeing [if groups are] on task, or if [a student] is kind of sitting back. […] I was walking [towards one group where a student] was trying to get into the conversation, and the girls were kind of dominating things, but he eventually got in a few of his ideas. So I just sort of stepped back.

Class discussion.

"If this happened in real life, scientists would do just what you did."

After ten minutes of small group work, Tom called the class together for a larger discussion. They reviewed some of the movie facts, hypotheses, and learning issues the groups had identified. Throughout the discussion, Tom often encouraged the students to add items to their lists of learning issues.

While discussing their movie facts one of the students in the second class said, "They were taking ice samples from different depths. […] I think that's what [scientists] really do".

Tom responded, "So you think scientists really take ice samples in Antarctica. So we can probably learn more about that, don't you think?"

"Yeah".

"So you can write [that] down under learning issues: What were they trying to collect?"

"Samples". The girl seemed to interpret the potential learning issue as a question.

"Samples of what?"

"Air. Like air might be trapped in the ice".

“That’s a good learning issue: What were they looking for in the ice?”

I am asserting that Tom has a good understanding of climate science, and later I will elaborate by discussing his knowledge of ice core sampling. If Tom ran a more teacher-centered classroom, he could have easily told the class how scientists use data from ice cores as temperature proxies or to learn about ancient atmospheres, but he didn’t. Instead, he urged the student to add it to the list of questions that she might look into herself.

In concluding the discussion, Tom said, “If this happened in real life, scientists would do just what you did. They would come up with a bunch of hypotheses, and then they would try to find out more information to see which ones are more likely or not”. Tom never mentioned the NGSS in any of our discussions, but I would argue that Tom was explicitly asking his students to engage in the scientific practices of “Asking questions” and “Constructing explanations” in preparation for “Obtaining, evaluating and communicating information”.

Scene two: UN conference.

“We have a lot of unanswered questions, but we’re going to spend the next couple of days trying to figure out more about this.”

Tom introduced the next scene by saying, “In this movie, the scientist who jumped over the crack has a hypothesis. And in this next scene, we get to learn about his hypothesis”. The other teachers distributed handouts (see Appendix F1) as Tom explained, “There are a lot of big words in this scene– and a lot of big ideas”. He reviewed each of the vocabulary words on the handout, before showing a two-minute scene set at a UN Conference on Global Warming, in which part of the movie's premise is set out: The melting of Arctic ice prevented the flow of the North Atlantic Current thereby plunging the planet into an ice age 10,000 years ago.

Tom stopped the DVD and asked for volunteers to read the shortened version of the scene he provided in the handout. When the students were done reading, he told them that some of the ideas in the scene might be confusing, and they should "take a minute to jot those down under learning issues. […] We have a lot of unanswered questions, but we're going to spend the next couple of days trying to figure out more about this".

Day Two: Introducing Climate Change

"Instead of talking about global warming, we're going to talk about climate change."

As the students entered the room, their box charts from the day before were laid out on their desks. Tom asked the class what the movie's scientist hypothesized as the cause for the Ice Shelf collapse.

A student answered, "Global warming".

Tom explained, "Instead of talking about global warming, we're going to talk about climate change", and promised that the class will have a chance to find out the difference. He then introduced the trailer to *The Day After Tomorrow*, by saying, "In the movie, besides the Larsen B Ice Shelf breaking apart, […] all sorts of things happen. We're going to watch [the trailer] to find out what else happens in the movie. […] Your job is to try to identify as many things as possible [that the movie makers think might happen] because of a warming Earth".

The trailer showed a series of natural disasters culminating in an image of New York City covered in ice and snow. As each event flashed on the screen, Tom listed them, "There's flooding. […] Tornadoes in California. Storms. Birds flying south. More flooding. Big giant wave. And New York City: Is that a snowy day or something else? […] If you want to know if this could really happen, you can add that to your learning issues: Can all those weather events really happen?" As he spoke, he switched to the powerpoint slide in Figure 22.

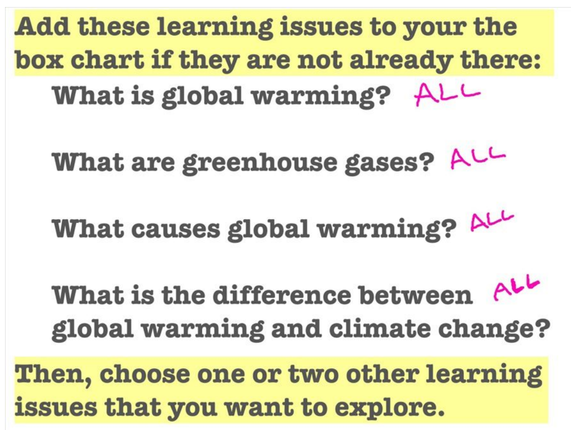

FIGURE 22
Powerpoint slide: Learning issues for the students' box charts.

Introducing the day's activity.

"What is global warming, and how is it different from climate change?"

Tom explained that the movie was science fiction, and to figure out if the events in the movie could really happen, they would need some background information. He told the class to look at the learning issues on their box chart, and if any of the questions on the slide weren't already listed, they should add it to the chart, and write the word "all" next to the question, indicating that everyone in their group should research those questions. Then they should look at the rest of their questions, talk about if they had any more questions, and then divide up responsibility for the remaining questions, with each student putting his or her initials next to the questions he or she would work on.

The students spent five minutes working with their groups as the teachers walked around the room offering guidance and encouragement. Then Tom called for the class's attention, and told them that they would have several days to research their learning issues, but that they would start by focusing on the four questions on the powerpoint slide above (Figure 22). He also explained that there would be a "Ticket out the door". Pointing to the rightmost whiteboard, he said that as they conducted their research they should be taking notes in their composition books on "What is global warming, and how is it different from climate change?"

Next, he showed the class how to navigate to a website he had developed for them to use in their research (see Appendix F2). Starting at the home page, he briefly discussed each of the eight pages within the site, and told the students that they would focus on the page titled "Basics" for the rest of the day. The teachers then distributed laptop computers to pairs of students. The special education teacher took several students into the hallway, and the class got to work.

Later, I would ask Tom about the resources he used in developing the unit, and he said, "We don't really have a textbook that digs into [climate change], so it is really […] one hundred percent web-based". The lack of textbook coverage is not surprising given that the GPS don't mention climate change, but Tom found abundant age-appropriate resources. Eleven of the 27 links in Tom's website (see Appendix F2) went to a site called *A students' guide to global climate change*, maintained by the Environmental Protection

Agency (EPA, 2013). Many of the other links also went to sites targeted to young people.

Ticket out the door.

"[Your classmate] said that climate change is changes in the average temperature–global warming–plus more. And she's right."

With five minutes of class time left, Tom asked the students to log off their computers, and the other teachers collected the laptops while Tom led a class discussion about the "Ticket out the Door". First he asked, "What is global warming?"

One student said, "When the Earth gets warmer".

Tom responded, "Awesome. So, if tomorrow it's warmer than today, is that global warming?"

A number of students called out, "No", and one added, "It's an increase in the average temperature over a long period of time".

Tom responded, "Awesome" and repeated the student's words as he lowered a sheet of paper that was covering the leftmost whiteboard to reveal his definition of global warming:

Global Warming – refers to an <u>*increase*</u> *in the Earth's* <u>*average*</u> *temperature.*

Then he asked, "How is global warming different from climate change?"

A student offered a very detailed answer, and Tom responded:

> Wow, that was a really good answer, and you said a lot. Let me summarize for everyone, and please correct me if I'm wrong. [Your classmate] said that climate change is changes in the average temperature–

global warming–plus more. And she's right. It's not only temperature change, but it's also changes in precipitation patterns, like rain and snow, and changes in wind patterns over a long period of time.

As he spoke, he removed the sheet of paper from the whiteboard, so students could see both definitions:

Global Warming – refers to an <u>*increase*</u> *in the Earth's* <u>*average*</u> *temperature.*

Climate change – refers to major changes in temperature, precipitation, or wind patterns for a long period of time.

These two definitions would remain on the board for the next two days. Taken together, they communicated the key distinction between global warming and climate change without being too complex for 6th graders to understand.

Day Three: Greenhouse Gases

"Without the greenhouse effect, the Earth would be 33 degrees colder than it is now."

Tom started class by asking the students to review the difference between global warming and climate change. Then he displayed a powerpoint slide and explained that today's "Ticket out the Door" would involve answering three questions:

1) What is the difference between global warming and climate change?

2) What are greenhouse gases?

3) What is the greenhouse effect?

The students worked independently for 30 minutes, until Tom asked them to log off their computers, so they could discuss the day's "Ticket out the Door". After reviewing the difference between global warming and climate change, he asked, “What are greenhouse gases? What do they do?”

A few students offered replies, and Tom said, “A lot of people say they trap heat, and that's good. But you can also say they absorb heat, and that's a little better. [Either way], they keep our air warmer than it would be otherwise”. Then he asked, “What are some greenhouse gases?”

Various students offered answers: “Carbon dioxide”, “methane”, “nitrous oxide”, “water vapor”.

The class continued to discuss the greenhouse effect for about five minutes. At one point, a student said, “Without the greenhouse effect, the Earth would be 33 degrees colder than it is now”. Listening to the review, I had the strong impression that the students had largely mastered the material Tom had asked them to learn that day.

Tom ended the class by asking, “Are there things in nature that cause greenhouse gases to be in the air?”

A chorus of students called out “Yes”.

“Are there things that humans do that cause greenhouse gases to be in the air?”

“Yes”.

“So who’s responsible for the fact that the Earth's temperature is going up?”

A number of students responded: “Us”, “Humans”, “People”.

“What about things in nature that make greenhouse gases? Can they be responsible?”

A number of students called out various answers, and Tom said, “OK guys. We're going to pick up on that point [next time]. Good job”.

Day Four: Elevator into Space and Natural vs. Human Cause

"There's not one perfect way to do it, but I prefer it to be more student driven."

As the students entered the room, a powerpoint slide displayed the day's warm up activity:[31]

1) Get out your composition book. Review your answers to these questions:

What are greenhouse gases?

List three of them.

2) Then, make a prediction: How much of the earth's air is carbon dioxide? I think our air is _____ % carbon dioxide. Write your prediction in your composition book.

Tom started class by asking the students to review the greenhouse effect and to share their predictions for how much of the atmosphere is carbon dioxide. The students made guesses between 30-50%. Tom explained that they didn't have the equipment to do a lab measuring the level of carbon dioxide in the air, but they would do "the next best thing"–an online activity called *Elevator into space*. He explained that the activity would take about 15 minutes, and when they are done, they should go back to his website, and look at the page on "Natural vs. Human Cause", so they could answer today's 'Ticket out the door':

1) How much of the earth's air is carbon dioxide? Are you surprised?

2) What things <u>in nature</u> add greenhouse gases to the air?

[31] A similar warm up activity started almost every class. I have omitted them because, as with item (1), they usually involved reviewing the previous day's work. In this case, item (2) was looking forward.

3) What other things <u>in nature</u> may cause the earth's air to warm?

4) What <u>human activities</u> add greenhouse gases to the air?

5) Nature vs. Human Activity: Who is to blame for our rising temperature?

Tom explained that they would work in pairs, and demonstrated how to do the activity. While he did this, the other teachers distributed the handout (Appendix F3) that the students would use to record their work. The *Elevator into space* activity didn't mention CO_2 levels, and CO_2 was counted among the "other gases". Tom didn't alert the class to this complication. Instead, the teachers helped pairs of students think through the issue as they worked.

As the class worked, I observed Tom and also helped some students myself. This allowed me to reflect on how Tom and I interacted differently with the students. While Tom helped students understand the information on the website, I tended to provide them with information that went beyond what the website offered. Tom never discussed how his approach to teaching differs from that of other teachers, but in reflecting an experience with parent volunteers, he told me:

> It worked okay, but […] you'd have issues with the adults wanting to kind of take over the discussion, whereas I wanted it to be more student centered. […] There's not one perfect way to do it, but I prefer it to be more student driven.

After the students had worked for around fifteen minutes on the space elevator, Tom announced that they should start transitioning to researching their learning issues. The class continued to work for another fifteen minutes, before Tom announced it was time to discuss their 'Ticket out the Door'.

He started by asking, “Is there a lot of carbon dioxide in the air?”

A chorus of students replied, “No!” A couple of voices added, “Less than one percent”.

Tom then asked the class if they were scientists, how they might try to figure out if the current warming was more a result of human activity or nature.

The students suggested a number of ideas, including looking at the bubbles in ice cores to see how high carbon dioxide levels were thousands of years ago. Tom said that their ideas were all “awesome”, and they would return to the question the next day.

Day Five: Group Discussion

“[A]ccording to this graph, does it look like humans are contributing to global warming?”

Tom started class by announcing that the day's activity would be a group discussion. The students would have ten minutes to discuss their learning issues in their small groups, and then the whole class would come together to share. He recommended that they start with the questions labeled “All” on their box charts, before moving on to the other issues. If the conversation lagged, they had several questions on slips of paper in their ‘Stuck Jar’ (See Appendix F4), and they could reach into the jar, pull out a question, and talk about it.

The students got to work promptly, and Tom and the other teachers offered assistance and encouragement. When approaching a group, Tom often sat down and listened for a minute before saying anything. When he spoke, he often asked for clarification, like, “When you say ‘this’ do you mean global warming?” Sometimes he offered guidance on the process, like "OK, that sounds good; which question do you want to talk about next?" Sometimes, he asked probing questions, like, "Did the entire Larsen B Ice Shelf collapse, or just a part of it?" Occasionally, students asked him direct questions, but I never heard him provide a direct answer, instead he said things like, "Great question. If no one in your group had a chance to research that, make sure to write it down, so you can ask your other classmates".

After fifteen minutes, he transitioned to a full group discussion. He started by inviting the groups to pose any unanswered questions to the class. The first student he called on asked, "Is the Larsen B Ice Shelf a real place?" She called on someone to answer, and was satisfied by his response. Sometimes students asked questions that no one knew the answer to, like "How does an ice shelf form on the water?" and Tom would ask for "hypotheses". When a question touched on key concepts that Tom was hoping to get across, like "What is the difference between climate change and global warming?" he would ask the students for their thoughts, before offering a brief summary.

When there were about five minutes left in class, Tom asked whether scientists think human or natural causes are more responsible for global warming.

A number of students called out "Humans".

Tom asked for volunteers to explain, "What makes you say that?"

As the first student was speaking, Tom switched to a powerpoint slide, showing a graph from the 2007 IPCC report (see Figure 23). After calling on a second student, Tom drew the class's attention to the graph, and asked questions to help them read the graph, like "What's the x-axis say?" and "What's the label on the black line?" Then he explained that scientists make "these things called climate models" to predict how the

Earth's climate will change. They can use the models to see how the Earth might be if humans hadn't been releasing greenhouse gases into the atmosphere, and that's how they got the blue line.

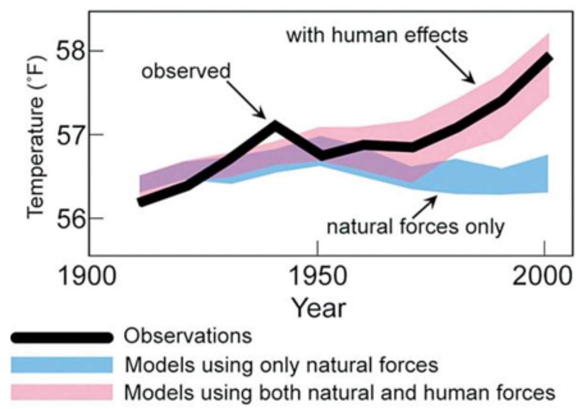

FIGURE 23
Powerpoint slide: IPCC Graph Comparing Human and Natural Forces
(Hegerl et al., 2007, p.703)

Then he asked, "Does the blue line seem to match the increase in temperatures we've seen?"

Several students said, "No".

"So let's look at the pink line. If the scientists add in greenhouse gases […] from humans, does that match better?"

Several students called out, "Yeah".

"So according to this graph, does it look like humans are contributing to global warming?"

A lot of students called out, "Yes".

In the second class, a student noticed that for a brief period, the observed temperature was above the predicted range for both sets of models. Tom responded by saying, “That is a good point”, and explained that climate models are imperfect, complicated, and are being refined.

This was the only time I thought Tom made a scientific misstatement. The colored bands represent 90% certainty (Hegerl et al., 2007, p. 703). If the climate models were perfect, you would expect the observations to be outside of the pink band about 10% of the time. If anything, the models may be overfitting the data, which calls into question the whole idea of using the models to show that the climate wouldn’t have warmed without human actions. This is a subtle point, and Tom can hardly be faulted if he didn’t appreciate it. Even if he had thought through the issues of margin of error and possible overfitting, he was probably right to use the opportunity to discuss the nature of science rather than offering a lesson on statistics that few 6th graders would grasp. I only mention it out to emphasize that I didn’t notice Tom making any *significant* scientific misstatements in around 20 hours of recorded instruction and interviews.

Then he displayed a quote from a recent IPCC report (IPCC, 2013c, p. 17):

> *It is extremely likely that human influence has been the dominant cause of observed warming in the 20th century. [Emphasis added on Tom's powerpoint slide].*

He briefly discussed the make up of the IPCC, and then read the text out loud, saying, “So they came to the same conclusion that you did based on that graph”. He pointed out that “extremely likely” is not the same as ‘100% certain’. Scientists will continue to do research, but “based on what we know now, it is extremely likely, according to the IPCC, that humans are responsible”.

The teachers then distributed rubrics, so the students could evaluate their own performance during the discussions. I am asserting that Tom created a safe and empowering learning environment; earlier, I suggested that he did this though hundreds of small actions. Tom empowered his students to grade their own performances in the class discussion, and this may not have seemed like a 'small action' to his students. Although I wasn't looking over the students' shoulders as they wrote, I had the impression they took the task seriously.

In addition to the rubrics, the students were given a Tree Chart to work on when they completed the rubrics. The class worked quietly for five minutes before being dismissed.

Day Six: Lab

"Have we done this experiment enough to come to a conclusion?"

Class started with a brief review, and then Tom introduced the lab: "Our experimental question for the day is 'Does carbon dioxide really act as a greenhouse gas to absorb heat?'" The students would work in small groups to answer the question by experimenting on models of the Earth made from 2-liter soda bottles (see Figure 24). One bottle would serve as the "experimental" and the other would be the "control". The control would have "regular old earth air". Reacting Alka Seltzer with water in a covered flask with a hose would produce CO_2 to pump "into our carbon dioxide earth". Then they would turn on the light, and take the temperatures in each bottle every minute for ten minutes.

FIGURE 24
Lab Set Up for Greenhouse Gas Experiment

I have done a very similar activity as a demo on a few dozen occasions. Care is needed to fill the container with carbon dioxide without it sloshing out. When done as a demo, it consistently generates data that illustrates that carbon dioxide heats up faster than air when exposed to light. As a student-conducted lab, it provided an opportunity to discuss the many sources of experimental error. For the last five minutes of the class period, Tom talked through the data generated by various groups. Some groups' data supported the hypothesis, while others' didn't.

They discussed the sources of error, and the possibility of redoing the experiment, but according to Tom, "If they redid it very carefully, and they got the same results over and over, then maybe their hypothesis isn't true". Tom asked the class, "Have we done this experiment enough to come to a conclusion?"

Several students called out, "No".

This was the only time in ten days of observations where I might recommend changes in what Tom did. Every experiment–no matter how well conducted–creates an opportunity to discuss sources of error and other reasons to question the results. The less obvious the flaws are, the better the opportunity to help students appreciate the subtle sources of error in any experiment. With greater care, I imagine the students could have the satisfaction of seeing their 'carbon dioxide earths' heat up faster than their 'normal air earths', and there would still be abundant sources of error to discuss.

Days Seven to Nine: Introduction to Geoengineering and working on projects

"[…] you'll decide whether this is something we should try or not."

Tom introduced their 3-day culminating activity by explaining that the students would be looking at some solutions that people are proposing to address climate change. Their job would be to learn about the solutions, talk about the good and bad points of each, and ultimately say whether they think particular ideas should be implemented.

Tom explained that there are two big approaches to dealing with climate change. The first is to block some sunlight, and the second is removing greenhouse gases from the air. He then turned to the screen (see figure 25), pointed to the word "geoengineering", and started the longest powerpoint presentation I observed over ten days of teaching. A complete transcript of the presentation follows.

FIGURE 25
Powerpoint Slide: Geoengineering

“All of these ideas fit in a category called ‘geoengineering’. Does anybody know what ‘geo’ means?”

A student called out, “Earth”.

“Right, so ‘geoengineering’ means ‘engineering or tinkering with the Earth’.”

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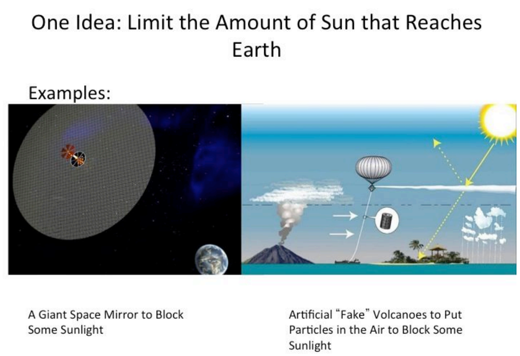

FIGURE 26
Powerpoint Slide: Limit Sunlight reaching Earth

“There are a lot of different ideas about space mirrors, but this is one concept. Artificial volcanoes. That's not a real volcano, so when you research that one, realize its not a real volcano”.

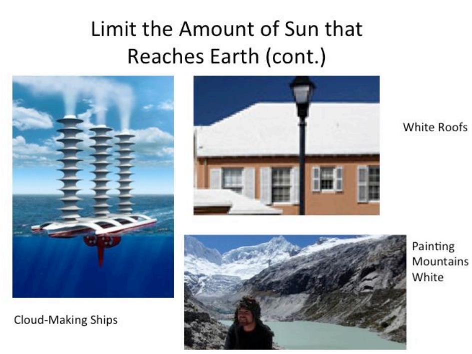

FIGURE 27
Powerpoint Slide: Limit Sunlight (cont.)

"Here's an idea about cloud making ships, white roofs, and painting mountains white. That's a picture from Peru. Those are all blocking sunlight from hitting the earth".

FIGURE 28
Powerpoint slide: Remove GHG.

"Here are some examples of removing carbon dioxide from the air. These things that look like little popsicles, that's the concept for artificial trees".

FIGURE 29
Powerpoint slide: Remove GHG (cont.).

"That's the idea for a seaweed farm. Dumping iron in the ocean. What artists think a desert would look like if it's all green. And this is storing carbon dioxide, in this case, under the ocean floor".

The entire presentation was completed in less than two minutes. At the end, a student asked, "How would dumping iron in the ocean help remove carbon dioxide?"

Tom answered, "Awesome. These are all things that you guys are going to research, so you're going to try and figure out how this would help with climate change, and you'll decide whether this is something we should try or not".

After doing their research, the students would make posters about their solutions. They could choose to work alone or in pairs, and most students decided to work with a partner. After Tom discussed the requirements for the assignment (see Appendix F5), the students picked their topics. Then, Tom distributed folders with readings about each topic (See Appendix F6).

For the next fifteen minutes, the students worked independently, as the teachers looked on and offered assistance. Some of the readings were difficult for the students, and as a result, Tom and the other teachers, spent a lot of time helping students understand the readings.

The students would work on their projects for two more days. Both class sessions started very quickly, and the students generally seemed focused on their work. Occasionally, one or two students might seem unfocused, and Tom would ask them to talk with him in the hall. Often when they returned to the room, the students quickly got to work.

I am asserting that Tom runs a student-centered classroom. This was evident in all of the class sessions I observed. In two of the sessions, Tom only addressed the whole group to remind them of what they needed to do at the start of the class and to announce when it was time to clean up at the end. Other than this, he and the other teachers in the room were offering support to individuals and pairs of students. Sometimes all of the students would be working independently, and the teachers would then talk to each other.

Day Ten: Sharing research on geoengineering ideas

"No easy answers here."

Tom introduced the final activity by telling the students about the next day's assessment. They would need to write about two geoengineering solutions in detail, including at least one big 'pro' and one big 'con' about each solution, and "most importantly, you're going to give your opinion about [both] solutions". The students could use their notes while doing the assessment, and Tom demonstrated how to take notes using "Painting mountains white" as an example.

He briefly explained the idea, which involved 'painting' a mountain with a white mixture sand, water, and lime. He reviewed the concepts of controls and independent and dependent variables. Then he showed a video,[32] and asked the class to pay attention to what the people in the video were measuring, so they could identify the dependent variable. The video was only five minutes long, but he stopped it in the middle to explain the idea of albedo (without using the word). After the video was completed, he demonstrated how they could take notes by filling in the top half of the note sheet that he had projected on the smartboard. Then he completed the second half of the handout with the help of the students who had researched space mirrors.

The class had fifteen minutes for a 'Gallery walk' in which they could look at each other's posters, and learn about the different geoengineering ideas. As the students shared their posters, Tom walked around, and checked in with each group.

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[32] http://edition.cnn.com/2011/11/28/world/americas/peru-mountain-whitening/index.html

After the gallery walk, Tom spent the last five minutes reviewing some of the challenges associated with geoengineering. He spoke for two minutes about cloud making, and raised a number of questions that highlighted the serious political challenges of addressing climate change. As he spoke, students responded to every question he posed, and many of his questions were in response to student comments.

> Who's going to be in charge of [making clouds to cool the climate]? Is it going to be an individual or is it going to be a country? If it's going to be the whole world, how would the whole world do something like that? Who would pay for it? If you say every country, is that going to be an easy thing, to get every country to pay? And how much should each country pay? And let's say a country like the United States decides that this is something we should do. […] Let's say we're able to make more clouds, and we're able to block some of the sunlight, […] can we control where the clouds go? […] And that might affect not only our country, but other countries as well. […] And there might be countries that don't like [other countries altering their climates]. So it's kind of a complicated thing, isn't it? So tomorrow, on your test, think about those things. Who would do it? Who would pay for it? And can you really predict how this solution might affect the climate? […] So it get's very complicated, no easy answers here.

Throughout my observations, I was impressed not only that Tom could communicate clearly to his students, but that hidden behind his sometimes simple statements lay a depth of understanding, not only of how the climate functions, but of the larger challenges facing the human community.

Other Issues

So far, I have focused on the first two research questions, which asked what and how Tom taught about climate change, and have touched on other issues when they clearly connected to particular aspects of his practice. Some of my assertions don't easily fit into the description of Tom's class, and I will turn to them now.

Resources.

Tom's skill, knowledge, and personality are his most valuable resources. Since the 6th grade GPS don't mention climate change, Tom's personal interest may be one of main reasons he teaches about the topic at all. His interest has motivated him to seek out other resources. He originally developed the unit as part of a summer workshop for teachers on PBL instruction, and since then he has twice been to Greenland to engage in climate research. The scientists he met in Greenland have become an important resource in his on-going learning about climate change. Tom also expressed a need for age-appropriate reading materials about geoengineering.

Abiding interest.

"I looked the original report, and [the new language] was much more definitive."

Tom has an abiding interest in climate change. In addition to twice going to Greenland to work with climate scientists, he has stayed up-to-date on climate news. In our conversations, Tom brought up the 2013 IPCC report three days after it was released, and said he had compared some its language with the language in the 2007 report. He discussed the Warsaw climate summit that was taking place as he was teaching, and explained that he didn't mention it in class, because he didn't expect "anything major to come of it". He also decided not to mention Typhoon Haiyan, which hit the Philippines as Tom was teaching about climate change, because, "in my understanding of climate change, you can't point to one storm and say, 'This is caused by human activity'." He was also aware of recent scientific research, and specifically mentioned the discovery of "an active volcano under Antarctica […] that might affect the ice melting down there".[33] Still, he decided not to discuss these other topics, because, "at some point [you] need to get to the basics and then move on". Tom provided his students with just the rudiments of climate science, but I had the sense that he had a deep understanding of climate science and this influenced his teaching.

Summer Research Expeditions.

"[…] a treasure trove of information […]"

When I asked Tom how he learned about climate change, the first thing he mentioned was his two visits to Greenland. His research looked at aerosols, and he learned a lot about the role of airborne particulates in the climate. But the camp where he lived was home to "researchers from all over the world", and he learned a lot from interacting with them. In particular, he mentioned learning about the "treasure trove of information about past climate" locked up in ice cores. Tom never specifically told that class why the scientists were drilling into ice in the opening scene of *The Day After Tomorrow*. But any students who were interested in the question, would have found a

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[33] This was news to me. The research had published two days earlier in *Nature Geoscience*, and had gotten some media coverage the day before. (Lough et al., 2013)

treasure trove of information available on the website he prepared for them, including a link to a journal he kept while on Greenland.

Age-appropriate readings.

"Those articles were not as easy to read and understand for the 6th grade reading level."

A quick review of Appendix F6 will show that almost all of the articles Tom gave his students about geoengineering solutions to climate change were written for adults. Tom expressed dissatisfaction with the readings:

> Those articles were not as easy to read and understand for the 6th grade reading level. […] I would love to have somebody […] take those ideas of geoengineering solutions and come up with […] articles that are just a paragraph or two on each [solution] and [provide] details [about] the good things [and] bad things about [each idea].

He also mentioned that he would like to have age-appropriate readings "about current research on climate change".

Institutional Factors

Tom is relatively unconstrained by the GPS, which don't mention climate change. His teaching decisions are more influenced by local conditions at his school, including the school's commitment to an International Baccalaureate (IB) curriculum, his collaboration with colleagues, and an administration that he says supports creativity.

Standards.

"We have a lot of freedom."

Tom and his colleagues have, "a lot of flexibility in what we teach: We've got the Georgia Performance Standards to guide us, but how we do that, it's not scripted. […] So we have a lot of freedom". Tom knew that the 6th grade GPS contain "nothing explicit about climate change", but this didn't prevent him from spending two weeks on the topic. In fact, Tom originally developed the PBL in 2005, when the 6th grade GPS focused on physical science. While the word "climate" appears once in the current 6th grade GPS, the current middle school physical science GPS don't even offer than tenuous connection. But Tom does not seem to be constrained by the GPS. In our first interview, he told me:

> Right now, we're studying ocean currents. […] The Georgia Performance Standards [say] kids need to know the causes of ocean currents. It's pretty cut-and-dry, pretty boring stuff. There's basically three causes for the ocean currents. But instead of having them read about ocean currents, we've created a problem based learning case [about garbage washing up on a beach in Hawaii]. So we take something that's cut-and-dry, "Here are the three causes of ocean currents", and make it [memorable].

Tom discussed the school's IB curriculum much more often than the GPS. When Tom originally developed the PBL, the unit culminated with the students putting on a "Climate Change Action Conference", to which they invited their parents and other members of the community. Tom switched to geoengineering for two reasons. First, it was "partially driven by the IB framework […]; [the students need] to look at a global or local problem and look at potential solutions […] and critique them". Second, "There is a big push for STEM". Tom didn't specifically say who is pushing for STEM, but his focus on geoengineering clearly anticipates the NGSS call to integrate engineering into science education.

Collaboration.

"Everyone's willing to do what it takes to help these kids learn."

Tom described his colleagues as "a great group of people", and reported that he works closely with them. His school's 6th grade is organized into three teams of teachers that work with three groups of students. Much of the collaboration happens within teams, and Tom's team focuses on meeting the needs of "struggling students" within the inclusion program. He said, "Everyone's willing to do what it takes to help these kids learn".

Tom had two very close collaborators in the classroom–a special education teacher and an experienced private school teacher who was pursuing public school certification. Their presence meant that Tom could devote a lot of class time to small group discussions without needing to personally monitor all of the groups. The special education teacher often took several students into the hall, which meant that the classroom was quieter than it would have been otherwise. When Tom went into the hall to work with the special education students, he wasn't leaving the rest of the class alone, because the student teacher would be in the room. One of the challenges of running a student-centered classroom is providing students with adequate support. Tom's collaborators did a lot to reduce this challenge.

Tom didn't discuss collaboration with the other science teachers in as much depth. The 6th grade science teachers don't follow the exact same curriculum map, but all of them teach about climate change at some point in the year, and they all make heavy use of the materials that Tom has been developing since 2005.

Support from administrators.

"[…] they let us be creative […]"

Tom spoke highly of the school's administration. "They don't micromanage us […], they let us be creative and try different ways to teach". Still, the administration is aware of what is happening in the classrooms: "They want to see our overall unit plan […]. We've got that uploaded on the computer, so parents can [see it too]". Administrators also visit each classroom about "15 or 20 times a year [for] 20 to 30 minutes at a time". Tom is used to teaching with two other adults in the room, and he didn't seem to mind that I was taking notes and videotaping the class. It seems possible that Tom is confident enough in his teaching ability that he doesn't consider the relatively frequent visits from administrators to be oppressive.

Socio-cultural factors

"I liked that discussion between the students."

Tom is focused on the sociocultural environment in his classroom. As I tried to show while describing his teaching practice, many of his actions are shaped by what he observes the students doing. When I asked Tom to reflect on his lessons after class, he often answered by reflecting on the students' interactions. For instance:

> Two girls were interviewing [a boy] about his poster on greening the desert, […] it wasn't like there was a grade involved, it was just [the girls] trying to understand things a little better, so I liked that discussion between the students.

Tom reported that the parents are generally very supportive of the school. In previous years, the PBL culminated in a “Climate Change Action Conference”, which many parents attended. On two occasions, parents voiced concerns about his teaching of climate science, but this wasn’t a huge challenge for him.

> [They were] years separated. One was very convinced that climate change, at least caused by human activity, was not a real thing–that it was all made up. […] The second person was concerned that we were indoctrinating the kids. But I talked with him, and he got very comfortable with the way were doing things, so that alleviated his concern.

Case Summary

Tom Butler is an exemplary teacher. He devotes two weeks of his curriculum to climate change despite the fact that it isn’t mentioned in the GPS for his course. Still, he doesn’t disregard the standards, and has made major modifications in his unit plan in response to his school’s IB focus. He works with a number of special education students, and they seem to enjoy success at a par with his non-special education students. He runs a student-centered classroom and effectively uses a PBL model of instruction. He introduced the PBL with a movie that is notoriously bad at presenting climate science, yet he brushed aside the inaccuracies and used the movie to introduce students to concepts that I did not see mentioned in most of the high school classes I observed. He took a clear, yet nuanced, stand on the controversial question of whether humans are responsible for the observed warming of the Earth's climate in recent decades. He introduced engineering into his science curriculum in a way that deepened his students' understanding of climate science while also introducing some of the political challenges inherent in addressing climate change. He was attentive to his students, and treated them with great tenderness.

Next, we will turn to Grace Chapman, who teaches elementary school students about polar bears. While I would describe Tom as 'awesome', Grace amazed me.

Case Five: Ms. Grace Chapman – Interest and Excitement

"Are you going to come back?"

Grace Chapman works at the same district science center as David Woolf, where she mainly teaches courses related to human anatomy and physiology. She also visits schools as a guest speaker and offers a 75-minute lesson called "The Mathematics of Climate Change" for 4th graders. I observed Grace teaching this lesson a total of four times at two different schools. My study of Grace's case prompts me to make assertions relevant to each of the research questions.

Research Question One (RQ1): What do teachers teach about climate change?

a) Grace teaches that polar bears face many challenges because of human activity.

b) She focuses on biomagnification of pollutants.

c) She teaches that polar ice is melting, but the reasons for the melting are debated.

RQ2: How do teachers teach about climate change?

a) Grace uses a variety of teaching modalities, including brief lectures, teacher-led discussion, a film clip, and a learning activity that involved math skills.

b) She adjusts her teaching to the local classroom environment.

c) She often anthropomorphizes polar bears.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) Grace's most valuable resources are her own skill, knowledge, and personality.

b) Her colleagues have been an essential resource in developing this lesson.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) Grace embraces the science center's mission to excite young people about science.

b) She says that the opportunity to teach lessons many times allows her to refine her lessons.

c) She says that science center's administration encourages its staff to develop new lesson plans.

d) Her collaborations with other science center staff have supported her efforts to teach climate change.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) Grace acknowledged the political controversy around climate change but avoided framing it as a scientific controversy.

b) She and her colleagues have a shared interest in environmental stewardship, and this shaped the lesson they developed as a team.

Synopsis

I observed Grace presenting a lesson called "The Mathematics of Climate Change" to four groups of students at two different elementary schools within ten miles of downtown Atlanta. We visited three different classrooms, but the rooms were similar in many ways. All of the classrooms held between 28-35 students, with an even mix of boys and girls. In the first school, which I will focus on in my description, almost all of the students seemed either Asian or Hispanic, though two students seemed African-

American. In the second school, about two-thirds of the students seemed African-American, and the rest seemed Asian or Hispanic. All of the rooms had desks clustered with the students facing each other, making it easy to transition into group work. All of the classrooms had screens in the front of the room on which Grace could project her Powerpoint, and Grace always used a handheld remote to advance the slides as she walked around the room. Grace had 80 minutes with each class in the first school, but she had only 40 minutes with each class in the second school. She was skilled at adjusting her presentation to the different time constraints, and the two sets of classes felt very similar to me. Still, Grace voiced some frustration over the time constraints at the second school, though she still enjoyed her contact with the students. As she told me in an interview after one of the shorter classes:

> Did you see the little boy at the end? He said, "Thanks for coming" and gave me a hug […]. He said, "Are you going to come back?" and I said, "If I do it will be for fifth grade" and he said, "Well, if I see you, I'll hug you again then, too".

The Mathematics of Climate Change

"I've been doing it for so long that it seems to come […] natural."

Grace caught my attention the moment I entered the classroom, though it took me a few seconds to recognize her. When I met her at the science center, her dress was casual, but for the school visit, she put on a tan pantsuit, with a black blouse, large gold earrings, and a black fedora. I am asserting that Grace's skill, knowledge, and personality are valuable resources; self-presentation is an aspect of personality. When

Grace was acting as a guest speaker in elementary schools, she dressed, not like a typical elementary school teacher, but like a woman being interviewed on TV. In both manner and attire, she carried herself with dignity and refinement. Even before joining the science center's staff over ten years ago, Grace was teaching about reproductive health, and in her current position, she visits schools to talk about "Reproductive Physiology and Puberty" with teenagers. I suspect that Grace has developed an open and self-possessed teaching style, at least in part, to meet the rigors of discussing sensitive issues with young people with whom she has no prior relationship. If she originally adopted her manner of self-presentation to meet the demands of teaching Sex Ed, it seems to have become ingrained in her personality: "I've been doing it for so long that it seems to come so natural that […] whatever techniques [I'm using] I'm not even conscious of anymore".

Learning Goals.

"Where science [turns into] adventure."

The first slide of Grace's presentation told the students what they would be learning that day:

Today we'll learn:

- *How does food energy flow within an ecosystem?*
- *What affects the survival or extinction of organisms in the Arctic?*
- *Why is ice important to the polar bear?*
- *How is the climate of the arctic changing?*
- *What is biomagnification?*

Grace told me that she had goals beyond those listed on the slide:

> I don't tell them, but I'm hoping that they take away […] an interest in environmental issues where they want to learn more about what's going on in the world, or how [humanity] impacts the environment. So, […] I hope they […] learn that there are things that humans do that affect animals and that affect our environment, and that we need to [do] something differently if we don't want the polar bear to go extinct.

The first goal of Grace's unspoken goals involved student "interest", which she later connected to the science center's mission and motto:

> We'll go to the school and present science in what we hope is a very interesting and engaging way, and they just get so excited about it that they want to learn more about it. So, […] we say [the science center] is where "Science [turns into] adventure".

Interest and learning feed back on each other. The more you learn about a topic, the more interesting it can become, which can stimulate more learning. As a guest speaker, Grace cannot initiate this feedback by stimulating deep learning, or even deep interest, but she can stimulate excitement.

The Arctic.

"We haven't gone over that yet."

Grace involved the students in the discussion right away. In discussing the first learning goal, she said, "Raise your hand if you can tell me what an ecosystem is".

Several students raised their hands, but it turned out that none of them actually knew the word, and the teacher explained, “We haven’t gone over that yet”.

I am asserting that Grace adjusts her teaching style to the local classroom environment. I have already noted how she can fit a 75-minute presentation into a forty-minute timeslot. The lesson aligns with fourth grade life science GPS, which include “ecosystems”, “food chains”, “adaptations”, and “extinction”. Some classes have already covered the content in depth, but some may not have encountered it yet. Grace needs to quickly assess how familiar the students are with the content standards, and “then I may spend a little bit more time on […] review”. By starting the lesson with a question linked to the content standards, Grace is able to adapt to the needs of each class while she still has maximum flexibility with time.

The slide’s final bullet point discusses biomagnification, which is not included in the fourth grade GPS. When she got to the last point, she did not ask the students to explain the word’s meaning. Instead she said, “that seems like a big word, but you’ll see that it’s very simple”.

The next few slides showed pictures of the Arctic, and Grace presented a ten-minute geography lesson. Several minutes were spent discussing the slide in Figure 30. Grace led the discussion by asking questions like, “Which country has the largest Arctic population?” and praising students when they answered her questions correctly. Although the graph was more complex than most graphs used in elementary school, most of the students seemed to be able to make sense of it. Grace took the geography component of the lesson very seriously, and even discussed topics unrelated to Arctic geography, including a mnemonic for the Great Lakes going from west to east that I have committed to memory.[34]

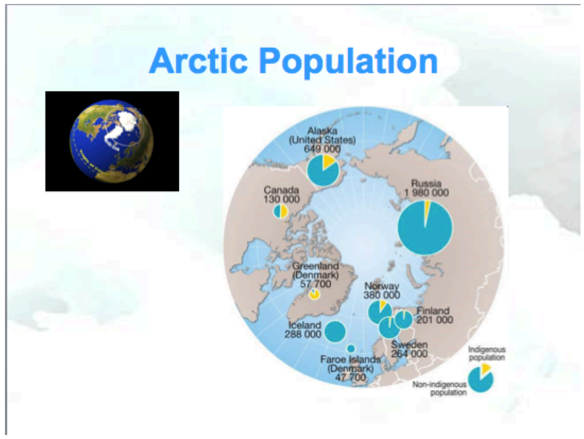

FIGURE 30
Powerpoint Slide: Arctic Geography

She then turned to Arctic ecology and started by saying that parts of the Arctic are covered by land, parts by water, and parts by ice, before discussing some of the animals and plants that live in the Arctic. The discussion focused on the idea of adaptation, and after a few minutes, she turned the class's attention to the polar bear.

Why is the polar bear lonely?

"Whatever we want to call it–global warming, hole in the ozone, climate change, greenhouse effect: Something is causing the ice to melt."

About thirty minutes into the class, Grace started discussing environmental change for the first time, while discussing a slide that offered answers to the question:

[34] SuperMan Helps EveryOne.

Why is the polar bear lonely?

- *There are fewer and fewer polar bears.*
- *His world is changing.*
- *The ice he needs is disappearing.*
- *The Arctic is becoming polluted.*

Grace discussed several environmental challenges confronting arctic wildlife, and spent five minutes discussing "pollution" in the form of garbage that ends up in whales' stomachs. During the discussion, she projected an image of a dissection of a dead whale, focusing on the stomach contents. She emphasized how important it is to avoid littering and advocated greater recycling.

She introduced climate change as a threat caused by "other pollutants". She said, "The ice he needs is disappearing. […] Whatever we want to call it–global warming, hole in the ozone, climate change, greenhouse effect–something is causing the ice to melt". This was the only time she explicitly mentioned climate change, and I found it interesting for two reasons: First, she conflated climate change and ozone depletion; second, she acknowledged the controversy, while asserting the scientific consensus.

I was not surprised to hear Grace conflating ozone depletion and climate change. This is a well-documented misconception among lay people, and during our first meeting, Grace told me that she lacked professional knowledge of environmental science. It was also clear that she didn't distinguish ozone depletion from climate change:

> I never really even paid attention [to climate change]. I'd hear about it. But, as far as it relates to the Arctic, when doing my research [for this lesson], I incorporated some video clips from *Animal Planet* and then you

start to get a sense of what people are talking about when you see that it's actually affecting a living organism as opposed to a hole in the ozone layer

In acknowledging the controversy, Grace framed it not as a scientific controversy, but as something that politicians argue about. Grace later explained:

> Because there are a lot of political [aspects to climate change], I try to keep it open, because I don't know whose parents work in what. So I can't say, it's this or that. So that's why [I] say, "Whatever you call it, we know something is […] happening in the Arctic".

In one class, the host teacher responded to Grace's claim that "something is causing the ice to melt", by asking, "[Is it] being researched?"

Grace answered:

> Well, there're arguments over that, over what is actually causing this to happen. Some people say, "Oh there's no such thing as greenhouse effect; the hole in the ozone layer is not causing these things". So even at the national level we have politicians who are arguing over what is causing the problem. But regardless of what we want to call it, something is causing the ice to melt.

It seemed to me that by mentioning "research", the teacher was asking whether scientists debate the question of whether humans are involved in the melting of arctic ice. The social controversy over climate change turns on the question of what's being debated. One side argues that there is a legitimate scientific debate. The other side says the science is settled, and we're really debating what (if anything) to do about the problem. By acknowledging the debate, while framing it as political, Grace held firm on the central question, while seeming to take an open-minded position. She accomplished this with a few simple sentences, which speaks to my assertion that her own skill, knowledge and personality are vital resources.

The Arctic food chain and an exciting video

"We want to improve our businesses [...] and get our oil in ways that don't harm animals."

The class discussed the arctic food chain for about five minutes, and spent most of this time looking at a graphic about trophic levels that was shaped like a pyramid (See Figure 31).

FIGURE 31
Powerpoint Slide: Arctic Food Chain/Pyramid

After reviewing terms like 'producer', 'tertiary consumer', and 'omnivore', Grace discussed the idea of biomagnification, in a call and response between Grace and the students. She started it by saying, "If oil gets on the algae, like that big oil spill in the Gulf of Mexico, then the krill are going to eat the oil-covered algae. So they're going to get sick, which makes them easy prey for whom?"

The class called out in unison, "Krill".

"That's right, krill. Now the krill is moving slow, because what?"

"It's sick".

"So now the krill is sick. So that make it easy prey for whom?"

"The cod".

The call and response continued up the food chain to polar bears, and then Grace summarized:

> Polar bears are at the top of the food chain, and animals at the top of the food chain [consume more pollution than other animals]. 'Biomagnification' means that pollution is magnified up the food chain, and animals at the top, like the polar bear, get all the pollution from the animals below it.

The call and response seemed very effective to me. Biomagnification goes beyond the fourth grade standards; in fact, the words 'biomagnification' and 'bioaccumulation' don't appear in the GPS for any grade level.[35] Yet, the students were clearly involved and able to follow Grace's logic.

Next Grace showed short film of a polar bear hunting a seal[36]. It seemed to accomplish Grace's goal of stimulating interest in all four classes that I observed. As she later told me, "When the video is showing […], they are absolutely still".

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[35] I used Google to search the site www.georgiastandards.org for the words "biomagnification" and "bioaccumulation." Bioaccumulation is mentioned in one sample seventh grade lesson plan as a possible extension topic. Biomagnification didn't come up at all.

[36] See "Polar Bear Hunts a Seal" at: http://animal.discovery.com/tv-shows/other/videos/polar-bear-videos.htm.

Arctic ice is melting.

"I guess [the mother polar bears] know there's not enough food".

Next Grace projected a slide with satellite images showing the melting of Arctic ice over the last few decades. She explained how the photos were taken, and told the class, "We see that the ice is melting". She told the class that polar bears aren't good at sharing: If polar bears need to crowd together on less ice, they will fight, and "as a result life gets harder for the polar bears". Then she showed a series of five pictures of polar bears on ice surrounded by water, and discussed the particular challenges that the polar bears in the pictures might face.

Grace often anthropomorphized animals, as when she described members of the threatened polar bear species as "lonely". It became especially apparent in this part of the lesson. She described polar bear cubs as "babies", described hibernation as "sleeping", and explained the reason for a recent decline in average number of cubs per litter by saying, "I guess [the mother polar bears] know there's not enough food". While scientists might balk at anthropomorphizing polar bears, I suspect it helped Grace attain her goals of stimulating students' environmental awareness and interest in science.

How polluted is your polar bear?

"You all will kind of fix what our generation kind of messed up."

The culminating activity involved rolling dice and keeping score. As Grace said in our first interview, "I think the activity is wonderful; I try not to call it a 'game', but they do kind of play a game". She introduced the activity by projecting a copy of the game sheet (See Figure 32), as she and the other teachers distributed paper copies to the students while the teachers arranged the students in teams of four.

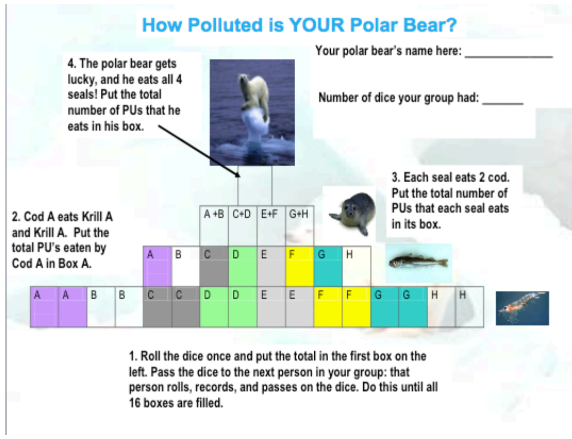

FIGURE 32
Game Sheet for Biomagnification Game.

Grace then explained the activity. Each group would get to name their polar bear, and would get either one, two, or three dice. Individual children would take turns rolling the dice to see how much pollution each krill consumed, and would enter the 'pollution units' in the bottom row of the sheet. Then the students would add up the amount of pollution in two krill, to get the amount of pollution in a cod that eats the two krill. Two cod would in turn pass their pollution on to each of four seals, and the pollution in all four seals would accumulate in the polar bear. No calculators were provided, so the activity gave students an opportunity to practice their addition skills. Grace invited four students to each roll one die, as she demonstrated how to enter the numbers on the sheet, and how to add up the pollution units to find how much would accumulate in one seal.

After the demonstration, the teachers used their discretion in giving each group either one, two, or three dice. I had the sense they were basing their decisions on how skilled the students in each group were at addition and how likely particular groups were to handle a large number of dice without distracting their neighbors. So the lesson's format provided an opportunity for informal differentiated math instruction.

The students seemed to enjoy the activity, and the math wasn't too challenging for any of the groups. In the first school, with the 80-minute periods, the students worked in their groups for about fifteen minutes. In the second school, with the 40-minute periods, they had less than ten minutes to complete the activity. Grace concluded the activity by asking groups to share their polar bears' names and how much pollution each polar bear accumulated. The students sometimes laughed when hearing the names their classmates had come up with, and seemed eager to share their "numbers". After all the groups shared, Grace concluded:

> In this game, […] the lowest number wins. […] Because the high numbers represent a lot of pollution, […] so if you have a low number, your polar bear might be healthier. […] So one die would mean you're in a clean environment, […], and three dice meant you were in a pretty polluted environment. [The polar bears' fate] is up to your generation. You all will kind of fix what our generation kind of messed up. We thought we were doing the right thing, but now it's leading to the ice melting and the polar bear maybe becoming extinct. And we don't want that to happen. So there are some things you can do. The United States produces more carbon dioxide than any other country, so you may want to do things like go to the Natural Resources Defense Council website, maybe do a class project about it. Some of your parents might change your light bulbs. […] Maybe your parents can get a hybrid car. […} And you might, when you

get older, vote for people in the government who want to protect the Arctic. […] When you get to middle school or high school, and you want to be class president, maybe you can say, "I believe in recycling, […] we need more recycling at the school". […] So things like that; just think about it.

Other Issues

In discussing Grace's lesson on climate change, I have touched on a few issues besides what and how Grace teaches about climate change. I hinted that her personal sense of style and her experience teaching sensitive topics with teenagers might help her command a class's respect while encouraging student participation and while handling the social controversy with great delicacy. I also said that her role as a guest speaker representing a science center committed to making science an "adventure" leads her to focus on engaging the students, in the hope that their excitement will lead to continued learning. Several other points didn't naturally fit into that discussion, and I will turn to them now.

Resources.

"I would look for [resources] that simplified it enough that I could relate it to an elementary school student."

Grace did not develop this lesson herself. Four people originally collaborated in developing the lesson–Grace, two other teachers, and an artist. All three teachers specialized in life science, "so this was a big change for us, and […] we didn't have any formal training in it”. This meant that they had to research and teach themselves about Arctic ecology in preparing the lesson. Grace described the research to me:

> I would look for [resources] that simplified it enough that I could relate it to an elementary school student. So, I wasn’t reading huge textbooks, [but I read] a lot of articles on it, and […] *Animal Planet* [had] really nice short videos that show the polar bear.

The Artist was a valuable resource in developing the game sheet. Originally it was black and white, but as the team refined the lesson, they decided to add color. Looking at the game sheet, I thought the colors were helpful cues to remind the children of which boxes to add together as they ascended the pyramid. But having taught the class many times, Grace highlighted another value of color:

> When you look at black and white, it looks like text. It might remind [students of] a book, maybe it feels more like work. […] But when you add the color […] it engages them more.

Grace’s work at the science center gives her access to valuable human and material resources. The artist’s skill likely meant that the handout was more attractive than it would have been had a science teacher developed it, but being able to ask the artist to create the handout also freed up time that Grace and her colleagues could devote to other tasks. Moreover, even though color printers are becoming more commonplace, many teachers might not be able to print out multiple copies of color game sheets.

Grace comes into to contact with a large number of science teachers, and she had several ideas for how the University of Georgia could support climate change education in the state.

1) She thought teachers would benefit from workshops to learn the content. She suggested that the workshops be presented locally, to save teachers' travel time. She said that the University might partner with other organizations, including the science center where she works, in putting on such workshops. While all teachers might benefit from workshops that presented content knowledge, she recommended focusing on "elementary school […] teachers [who] don't […] have a background in science". The workshops could also be videotaped and made available online.

2) She thought it would be helpful to have a webpage where teachers could download videos and other instructional resources that were vetted by the University.

3) She pointed out that many elementary school teachers lack materials for science activities, so they would prefer activities related to climate change using "household items" like "paper towel rolls". Alternately, the University could collaborate with experienced educators, like those at the science center, to develop activities using materials that could be provided in kits that could be borrowed and reused.

Institutional Factors

"You feel like you're doing a Broadway play."

Grace and her colleagues consulted the fourth grade GPS when developing this lesson. The standards make no mention of the climate or environmental change. Instead, they discuss several issues in community ecology, including food chains, populations, and extinction. She told me that in developing a new lesson, she and her colleagues "start with the GPS". They also ask what the teachers are likely to cover already; in this case "they talk about the animals in Georgia", but "we don't […] get a lot of [teachers] who talk about the polar bear". They also ask what might interest children; in this case, they decided polar bears are "cute and cuddly" and therefore appealing to children. Finally they ask, "Which concepts appeal to us personally?" In discussing the class with me, Grace said, "it's not just about climate change", and repeatedly brought up ways that she hoped students might learn to be better environmental stewards.

In her role as a guest speaker, Grace refines her lessons through repetition. She noted that in a self-contained elementary school classroom, teachers have to wait a year to refine a lesson by teaching it again, and high school teachers may "try it three or four times" before having to wait a year to further refine it. But "we can do it next month; we can do it in two weeks; we can do it the next day". Grace's personality may make her especially well-suited to the process of refinement through repetition. She told me:

> You feel like you're doing a Broadway play. You have four or five classes, you go into the first one and, "That didn't go so well, I didn't remember my script, I was off my mark". The next time you do it, you're are a little bit better and a little bit better, so after while the script is in your head. […] I kind of like that.

Sociocultural Factors.

"We all work together to design programs for the kids."

Grace spoke very highly of the science center staff and said she feels supported in her efforts to develop new curriculum materials.

> I have some of the brightest colleagues […] in the school system, and […] we all work together to design programs for the kids. […] You can go to

> them and ask questions, and they'll give whatever help you need to make your program better. I have really appreciated that.

She also reported that the administration is "extremely supportive". In particular, they have said that the teaching staff doesn't need to ask permission to develop new lessons. When they feel that a lesson is ready for field-testing, they need to inform the administration, but even then they don't need to ask for permission. She summarized by saying, "It gives us a lot of flexibility".

In her function as a guest speaker, Grace is less connected with the community she serves than most teachers. When I asked her if her colleagues at the science center support her decisions about how to teach climate change she said, "they don't know" how she teaches the topic. She said she that she had never received any parental feedback on her lessons as a guest speaker, and that the host teachers "seem to be excited" but she doesn't know "if they're just being polite". During the classes I observed, the host teachers were very supportive and involved, but Grace said this isn't always the case. "Some teachers […] really [help and] hopefully they've reviewed [the content] in the book or gone through the GPS for it". But for other host teachers, it's "like we're an imposition to them, like we're messing up their day. [So] I try to go out very humbly".

Still, she described the feedback she gets from students in consistently positive terms. One of the first stories she shared with me involved running into a student at the grocery store. The student had participated in a lesson she did at a local middle school that involved dissecting a pig's heart:

> A little boy remembered me and he told his mother, "I know her". So she stopped me, and I said, "Okay, hello". (I can't remember them; I see

hundreds.) And you never know if this is ever going to happen, but she said, "Because of you, my son wants to be a cardiac surgeon". Because I tell them when you are cutting a heart, you're being a surgeon and think of yourself as a cardiac surgeon. So that kind of touches your heart.

Still the lack of ongoing connection with students means these heart-touching moments are relative rare, "I don't have the long term relationship with [the students], so I never really see that 'aha' moment". If Grace's lessons on climate change inspire her students to take action, Grace is unlikely to hear about it. The most important sociocultural factor impacting her teaching is probably the support from her colleagues at the science center, and she feels well supported by that community.

Case Summary

"You hope that you can spark at least one child's interest."

Grace Chapman is a particularly interesting case because she teaches about climate change in an elementary school setting and in a class where the GPS makes no mention of the climate or of environmental change. She does this by exploiting the great autonomy she is granted in developing her lesson plans, which includes the freedom to pursue her own interests. Her and her colleagues' shared interest in environmental stewardship shaped their lesson, which addressed GPS about food chains and ecosystems while discussing a threatened species and environmental change.

The lesson looked at climate change as only one challenge impacting polar bears. It focused on less well-known problem–biomagnification of pollutants. Like climate change, biomagnification is best understood by looking at how pollutants function within natural systems. Just as food pyramids magnify the impact of toxic pollutants, feedbacks within the climate system magnify the impact of greenhouse gases. The connection is abstract, and may not be appreciated by Grace's young students (or by Grace and her colleagues), but the underlying principle is simple, and Grace did a good job of communicating it to her students.

Grace said that her job is to interest, engage, and excite her students, and she often returned to the theme in our discussions. As she told me in our final interview:

> You hope that you can spark at least one child's interest to go and learn more about it. I love that slide that has […] the two cubs walking beside the mother polar bear saying, "Their future is up to you". I wonder if they get it in fourth grade.

FIGURE 33
Grace's Final Powerpoint Slide.

CHAPTER 5

CROSS CASE ANALYSIS AND IMPLICATIONS

This concluding chapter will present the cross case analysis and discuss some implications of the work. It will end by reviewing some of the ways the teachers in this study said the University of Georgia could support their work and will suggest avenues for further research.

My study of the collective case prompts me to make several assertions:

Research Question One (RQ1): What do teachers teach about climate change?

a) Teachers varied in whether and how they defined terminology relevant to climate science. None of the teachers discussed climate forcing or climate sensitivity.

b) All of the teachers discussed the enhanced greenhouse effect as the sole driver of climate change.

c) The teachers varied in how much they discussed feedbacks within the climate system. While all of the middle and high school teachers mentioned water vapor as a greenhouse gas, none explicitly discussed the water vapor feedback.

d) All of the teachers focused on global climate change, and barely mentioned local or regional climate change.

e) None of the teachers debunked pseudoscience.

RQ2: How do teachers teach about climate change?

a) The teachers in this study used varied teaching modalities.

b) The large amount of misinformation about climate change available on the internet creates a special challenge for teachers who ask students to do internet research. Teachers varied in how they dealt with this challenge.

c) Three teachers did labs, which all involved making small models of some aspect of the climate system. These labs provided opportunities to discuss the challenges of doing science, but may not have offered insight into the climate.

RQ3: What resources do teachers use in teaching and learning about climate change?

a) The teachers' most valuable resources were their own skill, knowledge, and personality.

b) All of the teachers relied on teaching materials that they had developed themselves.

c) Other important resources included: other people, workshops, textbooks, mass media, and the internet.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

a) All of the teachers were aware of relevant GPS, and some were accountable to multiple sets of standards. All of the teachers went beyond the GPS.

b) All of the teachers said that they enjoyed administrative support. They all knew that I was recording our conversations, and that provides ample reason to question this assertion.

c) All of the teachers said they were constrained by time.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

a) This study provides no grounds to assert that climate change in the new evolution debate.

b) Most of the teachers presented climate change as a remote problem and offered simple solutions that their students could enact.

Though none of the teachers spoke directly to the point, I assert that the teachers in this study were all engaged in boundary work, involving multiple sociocultural boundaries. The boundary between lay people and scientists was especially salient for all of the teachers, and I will propose that other boundaries are particularly relevant to climate change education.

Cross Case Assertions

In this section, I elaborate on the core assertions. The next section will elaborate on the assertion that teaching is boundary work.

Research Question One (RQ1): What do teachers teach about climate change?

Only two of the teachers in this study offered clear definitions of the terms 'climate change', 'global warming', and 'the greenhouse effect'. The two definitions for climate change differed from each other. All of the teachers focused on carbon dioxide as the main driver of climate change, and few discussed local or regional climate change. None debunked pseudoscience.

'Climate change', 'global warming', and 'the greeenhouse effect'.

In Chapter One, I discussed the fact that the IPCC (2014a) defined climate change as either natural or anthropogenic, while the UNFCCC ("United Nations Framework

Convention on Climate Change," 1992) definition focused on anthropogenic climate change. I adopted the IPCC definition and said that I considered any long-term statistical change in atmospheric conditions near the surface of the Earth to be 'climate change', while 'global warming' refers just to increases in average near-surface temperature of the entire Earth.

The public may not understand the terms as the IPCC and I do. Whitmarsh (2009b) surveyed the British public and found that while many people use the terms 'climate change' and 'global warming' interchangeably, they often carry different connotations. In particular, survey respondents were 75% more likely to consider climate change "just a natural fluctuation" than were respondents who were asked about global warming.

Only two teachers in this study explicitly defined climate change. Tom's definition came the closest to the IPCC's. He said climate change referred to "major changes in temperature, precipitation, or wind patterns for a long period of time". He didn't focus just on temperature changes; he didn't specify whether climate change was natural or anthropogenic; and he didn't specify global changes. Jeff's definition was very different from Tom's. He saw climate change as referring to either global warming or global cooling, and, in defining climate change, he didn't refer to changes in climatic properties other than the average global temperature. Like Tom, he recognized that climate change can be either natural or anthropogenic.

The other three teachers focused on global warming, and discussed climate change within the context of 'pollution', thereby implying that it is anthropogenic. Although David and Annette didn't define 'climate change', almost all of their examples related to global warming, so 'climate change' and 'global warming' were effectively equivalent. Grace didn't discuss climate change in depth, but she treated it as synonymous with the ozone hole and the greenhouse effect. All of the teachers discussed the enhanced greenhouse effect as the sole anthropogenic driver of the climate change. None of the teachers mentioned 'climate forcings' or 'climate sensitivity'.

Postcarbonist perspective: Beyond "mean and/or variability".

If you understand social and natural systems as subsystems of the Earth system, then the question of whether climate change is mainly natural or anthropogenic disappears. The climate system contains a number of positive feedbacks, making it naturally unstable. In fact, the Holocene's unusual climatic stability may have been 'anthropogenic', resulting from the slow release of greenhouse gases and landscape changes associated with agriculture during an epoch when Milankovitch forcings would otherwise have triggered an ice age (Claussen, Brovkin, Calov, Ganopolski, & Kubatzki, 2005).[37]

If we are entering a period of unusual climate instability, then the idea of climate, as something that can be discerned by looking at averages and deviations, may no longer be tenable, and current research on climate change relies much more on regressions than on averages and deviations. The American Meteorological Society (2012) noted that, "the concept of climate has broadened and evolved in recent decades", and helping students grasp the evolving definition of climate may prove challenging for many teachers.

[37] Claussen's thesis is controversial. From a postcarbonist perspective, humanity is part of the climate system just as climate history is part of human history. Whether or not the Earth would have experienced an ice age without pre-industrial greenhouse gas emissions is less important than the understanding that agriculture has been part of the Earth system for thousands of years.

Focus on carbon dioxide

All of the teachers emphasized carbon dioxide as a driver of climate change. While teaching elementary school, Grace mentioned the gas only in passing, which is appropriate given few fourth graders know what carbon dioxide is. But she talked about "pollution" in depth. In discussing steps that people could take to lessen the polar bear's plight, she talked about buying compact florescent light bulbs or hybrid cars–actions that she presumably believed would mitigate CO_2 emissions.

Despite the fact that all of the teachers discussed carbon dioxide, none mentioned ocean acidification. And when a student mentioned it, Jeff responded, "I'm not going to tell you what that means now. " During an interview, he told me that his oceanography class would touch on acidification in discussing seawater chemistry. On the other hand, David and Annette both discussed acid rain in depth, framing it as a pollution problem that, like climate change, was linked to the burning of coal.

All of the middle and high school teachers talked about other greenhouse gases. They differed in how they discussed methane emissions from cows. Tom discussed cows as "natural", while Annette and David implied that cows were "unnatural" agricultural products.

Postcarbonist Perspective: Beyond Carbon

Chapter two of this dissertation included a graphic from the IPCC (2013c) report, which I said, "merits close examination" (See Figures 7 & 34). In particular, I pointed out that carbon dioxide accounts for less than half of the positive anthropogenic forcings.

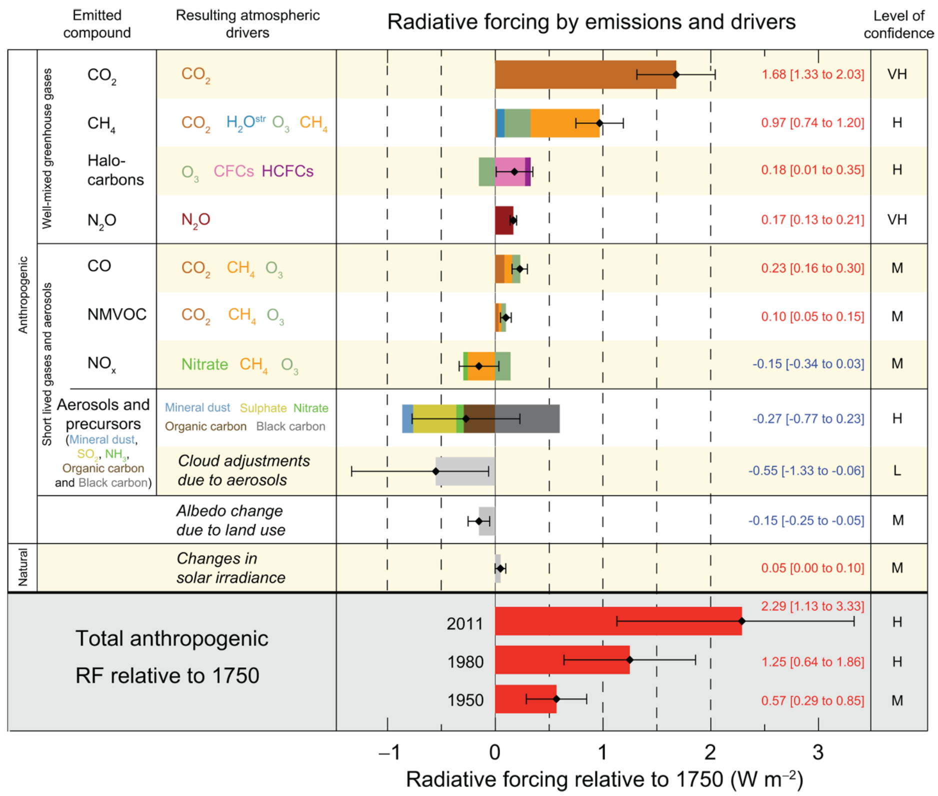

FIGURE 34
Overview of climate forcings. Carbon dioxide is the biggest single forcing agent, but it is not the whole story. It's not even half the story. (IPCC, 2013c, p. 14)

None of the teachers mentioned anthropogenic forcings other than greenhouse gases. Jeff mentioned "dust and ash" from volcanoes as a natural forcing, and Tom encouraged his students to research the idea of "artificial volcanoes" as a geoengineering strategy. David discussed the storage of coal ash as a problem for industry, but didn't discuss black carbon as a contributor to global climate change.

Carbon dioxide plays an important role in the climate system, and certainly merits attention. In particular, teachers may want to focus greater attention on ocean acidification, as another problem that is related to CO_2 emissions. Still, the almost exclusive focus on carbon dioxide is telling. Fossil fuel consumption is deeply embedded in contemporary American life. By focusing on carbon dioxide, teachers emphasize the problems associated with the American lifestyle, and may present the problem in a way that seems overwhelming to many students.

But postcarbonism demands that we look beyond carbon. Because of landscape changes, average temperatures in Metro Atlanta are increasing twice as fast as global temperatures, and the difference between urban and rural temperatures is acute and sometimes deadly during heat waves (Stone, 2012). As we stumble into the Anthropocene, we may find it easier to limit the emissions of black soot or to plant more trees in the urban environment than to withdraw cold turkey from fossil fuels. I fear that in our attempt to tackle the big problem, we are failing to take smaller actions that could have significant co-benefits, such as improved human health associated with cutting black carbon emissions (Kintisch, 2014). Students and teachers who advocate planting more trees in the schoolyard are likely to find allies even among parents who don't think climate change is real, and tree plantings will have greater impact on the local climate than school-wide recycling efforts. Students who are not aware of the many drivers of climate change may not realize what they can do to mitigate the problem.

Little Discussion of Feedbacks

David Woolf was unique in discussing feedbacks while introducing the topic of climate change. Annette explicitly discussed feedbacks, giving special attention to the ice-albedo and permafrost-methane feedbacks, but she did not emphasize them. In Tom's middle school class, he gave extra attention to the geo-engineering solution of "painting mountains white" which hinted at the importance of the ice-albedo feedback, but he never explicitly discussed the importance of feedbacks to the climate system. Jeff barely mentioned feedbacks, even though he devoted almost two hours of class time to a lab in which the students melted ice to understand the role of melting sea ice in the climate system. Grace didn't explicitly discuss feedbacks in the climate system, but her focus on biomagnification of pollutants hinted at how small human actions can interact with natural systems leading to big effects.

All of the teachers besides Grace talked about water vapor as a greenhouse gas, but none of the teachers mentioned the water vapor feedback. (David Woolf's passing mention of a possible "runaway greenhouse" came close, but he didn't discuss what might cause such a terrifying possibility.) Annette was the only teacher who mentioned the methane-permafrost feedback. None of the teachers mentioned the potentially disasterous methane hydrate feedback. None of the teachers explicitly made the point that a number of feedbacks make the climate system naturally unstable, so small human actions can have large effects.

Postcarbonist perspective: Feedbacks are central

Students may need to understand that a number of feedbacks make the climate system naturally unstable. From a scientific perspective the difficult question may not be why the climate is changing, but why the oceans have never completely frozen or evaporated over the planet's long history (Maher & Chamberlain, 2014). If slow feedbacks acting over millions of years have stabilized the long-term climate, then it raises the question of whether today's unprecedented rate of the change in the global environment may overwhelm these slow balancing feedbacks. If so, the current situation may be extremely dangerous. While it is much too early to reach such a conclusion or to discuss it in science class, teachers can help prepare future publics to understand potential worst-case scenarios by questioning why the climate has proved relatively stable over billions of years.

Unspoken assumptions are crucial to how people understand the world, and the assumption that the climate is unstable may need to overturn assumed climate stability. In emphasizing 'natural climate change', Jeff came closer than any of the other teachers to making this crucial shift.

Global Climate Change

All of the teachers framed climate change as a global problem, and some discussed how it might impact the local community. David exemplified this trend by talking about sea level rise on Tybee Island, and how climate refugees from Bangladesh might impact the United States. Annette was the most interesting case. Her experience as a gardener moved her to tell her students that she had witnessed climate change in her backyard and during her lifetime. But she framed the events in her backyard as a sign of global climate change, resulting from the enhanced greenhouse effect. Minutes later, she discussed the urban heat island effect, and framed it as remote–something that impacted Atlanta, but not the suburbs. The other three teachers rarely discussed climate change as a local phenomenon.

Postcarbonist perspective: Global and local

It is impossible to separate climate change from urbanization and from the urban heat island effect. Moreover urbanization is a global phenomenon, and the growth of urban heat islands impacts the global human population than any other aspect of climate change. Metro Atlanta's heat archipelago has sprawled in recent decades, and is likely to continue to spread. Recent decades have also seen an increased use of air conditioning and other technologies to control the human climate in Metro Atlanta. But these machines consume electricity, producing both carbon dioxide and waste heat, thereby exacerbating both global and local climate change. It may be important for students to learn about ways to adapt to increasing urban and suburban heat without exacerbating the underlying problem.

Addressing Climate Change

Most of the teachers talked about actions to mitigate climate change. David discussed the topic in depth, and recognized that in doing so, he was going beyond the GPS for his course. Tom's students spent three days researching geoengineering solutions, and Tom told me that in their next unit (on fossil fuels), they would talk about ways to reduce fossil fuel consumption. Annette often discussed environmental law with her students, and while I didn't witness her discussing the UNFCCC process or the regulation of carbon dioxide under the Clean Air Act, she told me that she asked her students to read about both topics. In talking with elementary students, Grace focused on pollution in general, and discussed recycling, using compact florescent lights, and purchasing hybrid cars as actions that might help polar bears. Jeff didn't talk about actions students might take to mitigate climate change.

Postcarbonist perspective: Adaptive Mitigation

Despite the widespread understanding that humans need to both mitigate and adapt to climate change, I saw very little discussion of adaptation strategies. David mentioned that people might move from Bangladesh to escape sea level rise, and his students indicated that they might leave Georgia to escape rising temperatures.

Metro Atlanta's schools can adopt adaptive mitigation plans to address local climate change. A number of approaches are possible, including modifying the schedule to encourage families to leave the city during August, planting more trees on the campus, or installing rooftop gardens that could be integrated into the school curriculum and supply food to the cafeteria. Project based learning units around climate change could be part of the process by which schools research and enact alternative adaptive mitigation strategies.

Pseudoscience

Although all of the teachers reported encountering unscientific alternatives to the consensus view, none directly addressed misinformation in class. In contrast, the books I reviewed written by scientists for the lay public all debunked common 'skeptic' arguments (Hansen, 2009; Kitchen, 2013; Mathez, 2009). While none of the teachers actively confronted misinformation, in the next section, we will see that most took pains to prevent their students from encountering misinformation.

RQ2: How do teachers teach about climate change?

The teachers in this study used a variety of teaching methods. Internet research and labs provide special challenges for climate change education.

Varied Teaching Modalities

Each of the teachers used varied teaching modalities, and there was great variation between teachers. David relied more heavily on powerpoints than the other teachers. Still his ninth grade geology class started and ended with his students writing and sharing their thoughts; both his geology and environmental science classes centered on a small-group activity incorporating math skills; and his geology class left the building for about 15 minutes to look at a solar panel. Tom used powerpoint much less than the other teachers; instead he provided students with a number of web-based resources that they could use to research climate change on their own, and then asked the students to share what they learned with their classmates. He framed the discussions around questions that he thought were important, and participated in those discussions by highlighting certain key points that students brought up. The other three teachers made moderate use of direct instruction.

Like Tom, Jeff and Annette both asked their students to do research on the internet. Annette referred to the activity as an "online lab", and it was highly structured. She adapted the activity from a workshop she had attended over the summer, and the students were asked to look at a small number of websites, and answer very clear questions about what they had learned from the sites. She chose this highly structured approach in part, because in earlier years, students had encountered misinformation while doing less directed research. Jeff set very clear guidelines about what the students needed to research, but did not limit the sources they could use. Given the amount of misinformation about climate change on the internet, it seems possible that some students might report misinformation to their class. Unfortunately, the IRB requirements forbid me from analyzing the student posters that I saw; I asked Jeff to record his summative discussion of the activity while I was observing another teacher, but he did not do so. So I have no data that would allow me to make any claims regarding the question of whether Jeff's students encountered significant misinformation in their research.

Three of the teachers had their students do labs, and the other two teachers had the students do math-related activities. In my subjectivity as a teacher, it is easier to come up with good lab activities for chemistry, biology, and physics than for Earth and space science. All of the labs provided the students with ample opportunity to discuss sources of experimental error, and all relied on mimicking small aspects of the Earth system. The math activities struck me as much more effective than the labs.

Postcarbonist perspective: Other approaches

In the previous section, I called for greater attention to local climate change, to adaptive mitigation, to feedbacks, and to drivers other than carbon dioxide. Such a shift in attention would create opportunities to adopt more varied teaching modalities. Tom's Problem Based Learning unit on global climate change culminated with his students' researching geoengineering strategies. If it looked at local climate change, students might ask how their school could adapt to climate change. In undertaking such a project, students might also learn valuable political lessons that transcend partisan divisions over climate change and foster democratic engagement.

Tom used a simple lab set-up to show that carbon dioxide can act as greenhouse gas. The experiment was almost designed to fail, because the carbon dioxide in their bottles could easily mix with the air. If the bottles weren't cut in half, and a bottle cap was used to seal the bottles, the experiment would likely provide much more satisfying results for the students. Similar set-ups could look into other greenhouse gases, albedo, diffusion of sunlight by aerosols, how soot accelerates the melting of ice, etc. Once exposed to the set-up and the multitude of factors that might impact global warming, students could easily come up with their own questions, and design their own experiments.

Students looking at local climate change might investigate local phenology by going outside and seeing when certain natural events take place, and then researching changes in the timing of these events. Students could do experimental studies by planting seeds in different microenvironments in the schoolyard and observing how microclimates impact biology, thereby providing a basis for predicting how climate change might change their local environment.

RQ3: What resources do teachers use in teaching and learning about climate change?

In this section, I will elaborate on my sweeping assertion in all of the individual case reports that a teacher's most valuable resource is his or her own skill, knowledge and personality. Then I will discuss several other resources that the teachers drew on.

A sweeping assertion: Skill, knowledge, and personality

I made the sweeping assertion that each teacher's "most valuable resources are [his or her] own skill, knowledge, and personality". The reader no doubt can accept the fact that I subjectively consider these very human traits to be vital resources for each of the teachers in this study. Still it begs two questions: 1) Does my subjective assertion impel the reader to accept the assertion as part of their subjective understanding of the world, and 2) Is there reason to believe that the assertion might hold for teachers in general?

I validated this assertion by member checking. Each of the participants reviewed their individual case reports, and none corrected this assertion. This was true despite the fact that I didn't say, "*Among the many* valuable resources at the teacher's disposal are his/her own skill, knowledge, and personality". Still this speaks to the teachers' subjectivities, and it does not command that readers accept the assertion.

Possible confirmation bias.

No doubt my subjectivity as a teacher played a role in the process that led me to make the sweeping assertion. The process started with my writing that, "David's own knowledge of climate science is his most important resource". As I watched the videotapes of his class, I got to the point where he told the meandering, yet fascinating, story of how petroleum came to play a central role in American life. I realized that he was using more than his knowledge. The unique workings of his mind wove his eclectic store of knowledge into a story, and then he told the story in an engaging manner, so I added 'personality' to the list. Later, while reading about his growth as a teacher in the interview transcripts, I added 'skill'. While working on Jeff's case, it was clear that his skill as a teacher was a vital resource, and I came to see that his teaching skill grew out of his personal commitment to self-improvement, and that he was also drawing of reservoirs of knowledge that he gained over years of teaching. In Annette and Tom's cases, I went through similar processes, and by the time I got to Grace's case, I just cut and paste the assertion into the draft before I even started watching the videotapes.

The fact that I brought Grace's case into the compass of the assertion before watching a minute of her videotaped classes provides ample reason to doubt the assertion's sweep, and therefore whether it applies to any of the cases. In Chapter 3, I wrote, "I like teachers" and discussed the dangers of conformation bias. I said, "whenever I perceive the threat of conformational bias, I will question my own bias, and will actively consider the possibility that I may be wrong". Ironically, in undertaking this process, I have become convinced of the assertion's sweep, and now assert that it likely holds true for all teachers.

Reductio Ad Absurdum.

To look into the possibility that my sweeping assertion might not generalize, I will look at David's case and ask what might substitute for his skill, knowledge, and personality. The recent movement towards scripted curricula is based on the implicit assumption that a script can, at least in part, replace a teacher's personal skill, and knowledge. It would be reasonably easy to develop a scripted curriculum based on this research. David Woolf will soon retire, and the science center will hire someone to replace him. I have videotapes of his teaching, copies of his powerpoints, his handouts, etc. I could develop a script for his replacement to read. At first glance, this might seem a possible substitute for David's skill, knowledge, and even some aspects of his personality. The science center might then add one item their job description, "to present a set of scripted lessons on climate change". The science center would be very unlikely to do this, but let's imagine they did.

Very few self-respecting teachers, especially those who are well-trained in geology and/or meteorology (the science center requires at least a master's in the teacher's subject area), would apply for a job with this description. But let's assume that someone did apply for the job, and that he or she had some self-respect. (Self-respect is an aspect of personality. The idea that someone who lacks self-respect might have the personality resources demanded of a teacher strikes me as absurd. But I set this argument aside.) In the classroom, the students would see their teacher reading from a script; they would notice that he or she would only answer questions that were anticipated by the scriptwriter. By reading from a script, the teacher would show the students that high school science is hard to master. In fact, even college and graduate study is not enough to master high school science. Why would the students study? Why would they even listen to the teacher? Wouldn't it make more sense for them to just read the script for themselves, or watch a videotape of David teaching? Why even hire a teacher unless he or she is bringing something uniquely human into the classroom?

The idea that a teacher's most valuable resource might be anything other than his or her own unique humanity is absurd. I started with the clear phrase, 'skill, knowledge, and personality' and concluded by arguing that it's absurd to hire teachers unless they bring something 'uniquely human' to the classroom. In making the sweeping assertion, I tried to name the unnamable, and I chose 'skill, knowledge, and personality' over 'unique humanity'. No doubt, my words fell short, but I stand by the assertion, and go further: I am convinced that this one assertion generalizes to all teachers.

I will return to the hypothetical idea of preserving David's lessons towards the end of this chapter.

A systems perspective on the sweeping assertion.

Each teacher's skill, knowledge and personality manifest in unique ways, but in analyzing each of the teachers as an evolving system, I discerned a common process. Each of these strengths may develop in a virtuous cycle (a truly positive feedback) that allows strength to build upon strength. David's knowledge of climate science allows him to access a broader array of technical and scientific resources than other teachers, which in turn deepens his knowledge. Jeff's reflective teaching practice helps him develop high levels of teaching skill. His district recognizes his skill and asks him to teach at the new teacher's institute, which gives him an opportunity to further reflect on his teaching practice. Annette's drive to learn her content motivates her to look deeper into the content that she needs to teach, which makes her realize how much more she needs to learn, which in turn feeds her drive to learn. Tom's commitment to student-centered learning leads him to embrace the practice. He sees it working with diverse learners, and this deepens his commitment. Grace's natural poise gives her the ability to discuss sensitive issues with young people, and her success gives her more confidence, which brings out her natural poise.

Interest not training.

Climate science is an emerging and rapidly changing field that looks at a changing and complex system. The National Science Standards (National Research Council, 1996) didn't mention climate change, so few science teachers have had deep exposure to climate science outside of the mass media. In fact, none of the teachers in this study had formal training in climate science. Even David, who earned a Ph.D. in geology, specialized in structural geology and started reading about climate science because of his personal interest. Tom was a lawyer before he became a teacher, and the other three participants in this study have backgrounds in biology.

David and Tom's cases show that an interest in climate science can initiate a positive feedback, in which interest stimulates learning, which stimulates deeper interest. Grace has training in biology and is interested in organismal biology, and developing a lesson about polar bears for elementary school students got her interested in the topic. Just as teachers work to stimulate their students' interest in hopes of initiating a process of lifelong learning, science educators who want to improve the quality of climate change education can work to stimulate teachers' interest in the topic. This may initiate a positive feedback that allows teachers to stay on top of a complex and rapidly changing field. Many schools ask biology teachers to teach environmental science, so one way to capture teachers' interest may be to connect climate change to biology.

The NGSS (Achieve Inc., 2013) emphasis on climate change will stimulate a lot of teachers to look for resources to teach the topic. This will create an opportunity for people with an interest in climate change education to stimulate teachers' interest in the topic. Accordingly, science educators who want to impact climate change education may want to know what resources (besides their own skill, knowledge, and personality teachers) look to in teaching about climate change.

Colleagues and scientists.

Other people were important resources for all of the teachers in this study. I mentioned several examples in the individual case reports: 1) Grace developed her lesson in collaboration with two colleagues, 2) Tom had two colleagues in the classroom as he taught, 3) Annette learned about the air molecule cards from a teacher at another school, 4) Jeff recruited my assistance in refining his lab, and 5) David used me as a resource to further his own learning about climate change.

Tom and David struck me as the most knowledgeable about climate science, and they made the greatest use of the local scientific community to continue learning. Tom's research experience on Greenland gave him, "access to some folks that know a lot about climate change". He learned a lot of climate science, by "just talking to the climatologists that were up there [in Greenland]". He's also maintained relationships, and "in the past, they've helped me look at some of [the science]". David participates in educational activities put on by the scientific community. In particular, he mentioned a series of science cafes sponsored by a local technical college, and a series of educational webinars put on by NASA and the National Park Service.

Two of my experiences suggest the other teachers are also interested in learning climate science, and that they may benefit from access to human resources that could answer their questions. In Annette's case report, I talked about how she used me as a resource to learn about the greenhouse effect. During the member checking process, Grace wrote, "After reading your work, I will certainly review the terms climate change, greenhouse effect, ozone depletion etc… in more detail […] not just for the student's sake, but for mine as well". I responded with an email that explained the distinctions in terms that an educated layperson could understand, and she expressed gratitude for the explanation. Grace, Jeff, and Annette are all motivated to learn more about climate change, but many written resources that discuss the topic with rigor would be hard for them to make sense of. Human beings can tailor their explanations to the individuals they are communicating with, and K-12 teachers might benefit from greater access to people with expertise in climate science.

Teacher developed resources.

All of the teachers in this study made heavy use of teaching materials they had developed themselves, including powerpoints, labs, webpages, handouts, and a game board. All of the teachers talked about refining their lessons over time, and the three high school teachers had a collection of computer files of materials they had developed and used years earlier. In looking through these files, it was clear that the teacher-developed resources were often modified every time they taught the course.

Tom's journals from his experiences on Greenland were the only teacher-developed student-readings developed by any of the teachers, and Tom had written these to fulfill a requirement for his participation in the expedition. Tom specifically said he would like age-appropriate reading materials about geo-engineering and current research on climate science, but for some reason, he didn't just write them himself. Given the variety of resources the teachers developed, I don't know why more of them didn't create documents for their students to read.

Workshop experiences.

Three of the teachers in this study participated in teacher training workshops related to climate change. I met Jeff and Annette at a workshop they both attended at a college in Metro Atlanta. As I discussed earlier, Annette used a lot materials from the workshop in her teaching, but the experience had much less impact on Jeff. In 2005, Tom and a colleague participated in a workshop at a local university. During that workshop, they developed the PBL that Tom continues to use almost ten years later. Tom has twice gone to Greenland to participate in a professional development program in which teachers learn climate science by doing climate research. When asked how he learned about climate science, the first thing Tom mentioned was his experiences on Greenland.

Mass Media

All of the teachers in this study mentioned mass media as one of the places they learned about climate science, and some used mass media in class. David turned to Michael Crichton in his efforts "to understand the opposing position". The science fiction author and screenwriter has testified to Congress about climate science, so it's not hard to imagine that other teachers have relied on Crichton's 'expertise' to learn about climate science and may have presented some of his work to their students, though none of the teachers in this study used Crichton in this manner. Jeff watches TV news and listens to conservative talk radio to learn about climate change, and Grace mentioned NPR as a place where she has learned about climate change. Tom and Jeff both used *The Day After Tomorrow* in class, and Jeff showed his students a History Channel documentary on paleoclimatology (Hearle, 2007). None of the teachers mentioned the film *An Inconvenient Truth* (Guggenheim, 2006), though Tom had a classroom set of books that accompanied the film (Gore, 2007).

The Internet.

The internet contains diverse media ranging from mass media to private listservs. All of the teachers used the internet to further their own learning and as a teaching resource. The teachers used a range of sites to further their learning: Grace turned to the Animal Planet[38] to learn more about polar bears, Jeff used Google Images to learn about Milankovitch cycles, and David downloaded technical reports to learn more about the Carbon Cycle. All of the teachers downloaded graphics and/or short videos to show in class, and three of the teachers had their students do research on the internet. Tom and Annette guided their students to prescreened websites, and Jeff gave his students more freedom in selecting their own sources of information. In previous years, Annette also gave her students freedom to find their own internet resources, but the social and political controversy around climate change has generated more misinformation about climate change than many other scientific topics, so she decided to limit the websites they used. All of the teachers besides Grace used government agency websites, including NOAA,

[38] www.animalplanet.com

the NRC and NASA. David used Google Earth. None of the teachers mentioned Wikipedia, TED Talks, or free online college courses.

Textbooks

Jeff and Annette were the only two teachers in this study who used textbooks. Neither used the textbook in class, but both assigned readings from the texts and used them as resources for their own learning. Jeff relied mainly on his assigned text, while Annette had a collection of textbooks that she turned to for her own learning, and provided her students with a xeroxed chapter of a textbook in addition to the book supplied by the school.

Postcarbonist Perspective

Schools are part of the Earth system and interact with the climate. All of the teachers in this study relied on their schools' infrastructure to do their work, but this infrastructure rarely became the focus of study. David was unique in talking about how individuals in the school could waste less electricity while in school, and he took the class to see a solar panel installed on the school's property. Jeff was also cognizant of the electrical infrastructure, though for a different reason: He knew that if he used too many hot plates, it might blow a fuse.

All of the teachers in this study developed their own teaching resources, and most of these resources focused on global climate change: Even when David showed his students the school's solar panel, solar energy was framed as a tool to mitigate global climate change, not as something that might improve life in Metro Atlanta or their school. Teachers might benefit from having tools that might help them develop resources that look at both science and adaptive mitigation in their schools and local communities.

RQ4: What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

All of the teachers discussed the relevant GPS, and many teachers were aware of the need to address standards beyond the GPS, though none mentioned the Next Generation Science Standards (NGSS). All said that their local administration supported their efforts to teach climate change, and all said that time limited their ability to cover climate change in greater depth.

Standards

All of the teachers in this study were aware of the relevant GPS, and all went beyond the standards. David and Grace both teach at their district science center, and were therefore expected to go beyond the standards in offering enrichment. Grace developed her lesson on polar bears after consulting the 4^{th} grade GPS, which includes a lot of topics related to community ecology, including food pyramids. In focusing her lesson on biomagnification, she introduced her students to a topic which is not mentioned in any K-12 GPS, but which clearly connected to the 4^{th} grade standards. David helped draft the Earth systems science GPS for the state as well as the SLOs for his district, so he was very familiar with the standards, and said, "the standards are supposed to be the minimum of what you're teaching". He also focused on the Earth Science Literacy Principles (Earth Science Literacy Initiative, 2009), which he considered important for citizens and future voters. Annette was aware of the relevant GPS, the Earth Science Literacy Principles, and the AP exam requirements. The need to conform her teaching to multiple standards sometimes stressed her, but she also felt that they were broadly in alignment with each other, and that she was successfully addressing all of them. Tom's

GPS did not mention climate change, but this didn't prevent him from devoting two weeks to the topic. His school's commitment to the IB program shaped his thinking much more than the GPS, and he told me, "I could go on about IB for days". The IB curriculum shaped his approach to student note-taking, assessment, and motivated his decision to devote three days of the ten-day unit to geoengineering. The GPS in Jeff's class focused on global warming. He felt this limited him, and he discussed global cooling along with global warming.

None of the teacher's voiced concern about End of Course Tests (EoCTs), though Annette was very focused on the AP exam. Jeff mentioned that there was no EoCT in Marine Biology, and said this gave him freedom to decide how much emphasis to give to each of the standards. One of the main criteria he used was his understanding of student interest, and he felt his students were more interested in marine biology than physical oceanography. Accordingly, he may spend less time on climate change in future years.

The NGSS emphasize climate change much more than previous standards, and this has gotten the attention of major media outlets (see Ludden, 2013) and the American Meteorological Society (2013). In 15 hours of interviews, over 50 hours of classroom observation, and untold hours of casual conversation, none of the teachers in this study mentioned them even once.

Administrative Support

All of the teachers in this study said that they felt well supported by their immediate administration, though two of the teachers did not feel supported by higher-level administration. Annette's department chair, Jeff, was very supportive of her efforts to teach climate change, but she said that the administrative staff was overworked, and was asking teachers to take on responsibilities that had been done by administrative staff in the past. In a similar vein, David spoke highly about the administration at the science center, but was less sanguine about the district, which he said failed to understand the center's unique value.

Having spent decades working in schools, I was surprised to hear such consistently positive comments about each of the teachers' immediate supervisors. In my experience, even teachers who are happy at their jobs and who get along well with their administrators sometimes complain about their immediate supervisors. I suspect that some of the teachers in this study felt constrained in talking to me, especially given that I was recording their comments, and would be providing a copy of this dissertation to their districts. In one interview, a teacher offered some fairly nuanced comments about the different administrators (s)he had served under, and specifically asked me to keep it "confidential"; Tom once joked, "I'm very happy with [the administration]… not just because you're tape-recording the interview". In fact, the teachers may have been careful in how they talked about a number of topics. At one point, Grace avoided saying the name of her employer. When I told her that she could speak freely, and I would edit the science center's name out of the interview transcript, she responded, "I [feel like] I'm on TV".

Time

All of the teachers felt constrained by time. Jeff and Annette both told me that because of interruptions due to standardized testing, pep rallies, and weather, they had lost almost a week of instructional time in their semester-long courses. David and Grace both developed their guest lectures to last for over an hour, but often had much less time to present the lessons. Even though Tom was teaching about climate change as COP 19 was taking place in Warsaw, he didn't mention the meeting or any of the international efforts to address climate change, in part because it would take time away from other topics.

Postcarbonist Perspective

Although I applaud the increasing emphasis on climate change in the NGSS, standards alone are unlikely to have a huge impact on teacher practice. In their examination of evolution education, Berkman and Plutzer (2010; 2011; 2012) found that teachers often act as street-level bureaucrats and use their own judgment in determining how to implement the standards. The teachers in this study all went beyond the GPS. Instead of focusing on the standards, those who are thinking about institutional reform might want to consider finding more *time* to teach about climate change. Given that climate change is relevant to both science and social studies, it may be important for those interested in science and social studies education to work together in carving more time out of the busy school day (see Sharma, 2012). From there, it may be possible to enter into discussions with teachers of math, English, and other topics.

RQ5: What sociocultural challenges and supports do they relate in their efforts to teach climate change?

All of the teachers in this study enjoyed job security, and are deeply embedded in their school communities. I found no evidence to support Pascopella's (2012) contention that climate change is the new evolution debate. In fact, instead of stirring strong emotions, the teachers in this study presented climate change as a remote problem that could be addressed by fairly simple actions.

The New Evolution Debate?

Berkman and Plutzer (2010) found that experienced teachers often exercise more autonomy when teaching about evolution than do less experienced teachers. All of the teachers in this study have been in their current position for at least nine years, and all have been teaching for at least 13 years. They all exercised autonomy in going beyond the GPS, but none acted to circumvent the standards.

None of the teachers in this study said they felt constrained by community norms in making curricular decisions. Annette and Jeff work in the same large suburban school, and serve the same politically conservative community. Their principal voiced concern about how the community would respond to their children learning about climate change, and I am virtually certain that the evolution debate impacted both of them several years ago. Jeff encouraged his students to research both sides of the supposed scientific controversy, while Annette presented the scientific consensus. Neither reported that any parents had ever questioned them on their approaches. While teaching both sides of the evolution debate is a common strategy used by teachers to manage the debate, in Jeff's case, I am convinced that he was presenting his best understanding of the science. Tom on the other hand, serves a community that overwhelming voted for Barack Obama in the 2012 election, and over the 8 years that he has presented a two-week unit on climate change, two parents have scheduled meetings to talk with him about how he approaches the topic. None of the teachers reported that their administration has ever questioned their approaches.

The teachers in this study all expressed awareness of the social and political controversy around climate change. But when this awareness impacted their instructional decisions, the impact was subtle. In earlier years, Annette allowed her students to do independent research on climate change, but found that some students would turn to unreliable sources, so she modified her instruction, so that the students would only use websites that she recommended. David relied on lecture, but he was careful to discuss the range of problems linked to fossil fuel consumption, so that, even if his students were swayed by anti-climate-science “propaganda”, they would realize that fossil fuels are still problematic. Grace was clear yet nuanced when a teacher asked a question that hinted at the controversy, and she told me that was careful in the language she used with students. Jeff was confused by the conflicting media messages, and this led him to present “both sides” to his students. But this wasn’t an attempt to satisfy the demands of the school’s politically conservative clientele; instead he was presenting his best understanding of the science. If the social and political controversy influenced Tom's instructional decisions, he didn't talk about it, and I couldn't discern the influence.

In my interviews with teachers about evolution, I heard stories of students disrupting class, teachers getting fired, and emotional abuse including one death threat. The five teachers in this study are a small sample, as were the seven in-service teachers I interviewed about their experiences teaching evolution. The ‘evolution’ teachers were all taking a course on teaching about evolution, and may have been motivated to take the course in part because they were experiencing challenges. On the other hand, the ‘climate change’ teachers needed the support of their administration to take part in this study. So no doubt, there was selection bias in both samples. Still, I have seen no evidence that “Climate change is the new evolution debate” (Pascopella, 2012).

A Remote Challenge with Simple Solutions

Most of the teachers in this study discussed climate change in both the present and future tenses, though they differed in how much they said it presently touches the local community. Jeff told me that he personally was convinced that the Earth is getting warmer and that polar ice is melting, but he was not as clear about these facts with his class. Tom and Grace indicated that climate change was currently melting polar ice; David played an animation showing that the United States has experienced more extreme heat events in the last 100 years; and Annette talked about how the daffodils in her backyard are blooming earlier than they did decades ago.

The teachers rarely connected climate change to specific events. The one exception may be Tom, who used the collapse of the Larsen B Ice Shelf in *The Day After Tomorrow* as a hook to get his students interested in climate change. Still, he was clear that they were watching a "science fiction movie", and never said that the idea that the collapse was linked to climate change was anything more than a "hypothesis". None of the teachers connected specific weather events to climate change, even though Cyclone Phailin hit India while the high school teachers were discussing climate change and Typhoon Haiyan hit the Philippines while Tom's students were studying the topic.

Many people think of climate change as a remote risk that will impact future generations and wildlife, but has little impact on their own lives (Lorenzoni, Leiserowitz, De Franca Doria, Poortinga, & Pidgeon, 2006; Whitmarsh, 2009b). Jeff framed current global warming and the melting of sea ice as uncertain, but he spent two class periods on a lab that indicated that if at some future point all the polar sea ice melts, the oceans will start to warm more quickly. David discussed how sea level rise and warming might impact Georgia in the next hundred years, and Grace focused on how climate change is a problem for polar bears.

While the challenge was remote, possible solutions were close at hand. David showed a DVD (Barrie & Southern Energy Conservation Initiative, 2008) that discussed many actions that students could take to lower their energy use while saving money. Grace told her students that they could save the polar bears by using trash cans instead of littering. Grace and David both discussed purchasing compact florescent light bulbs or hybrid cars as possible actions. Tom didn't discuss such actions during his climate change unit, but he told me that in his next unit, on energy resources, they discussed similar actions, along with healthy habits like walking or riding a bike instead of driving. Similar messages are often communicated in the media, and even advertisers market products as both good for the environment and economical. Whitmarsh (2009a) found that British government efforts to address climate change by asking the public to conserve energy were rarely effective, and that, to the degree they were effective, members of the public were more motivated by the desire to save money than by the intention to mitigate climate change. Such messages may be more effective when delivered in person by trusted people, but I am skeptical. I suspect they are more likely to blend in with the din of similar messages in the mass media.

Many of the teachers expressed confidence that their students could deal with the problem. David told his class, “I don't think this is insoluble, or I wouldn't be teaching you this stuff”. Grace expressed a similar sentiment, telling her nine-year-old students that they were going to determine whether or not polar bears go extinct. Annette said that by 2020, when her students graduate college, they “will be out making a change in the world". None of the teachers discussed mitigation actions that might not directly impact fossil fuel consumption. None of the teachers discussed adaptation.

Postcarbonist Perspective

David was the most radical teacher in this study. He told his students, "We need to kind of change how the economy works", and discussed the possibility of a carbon tax. None of the teachers even hinted at the possibility of major systemic change. By indicating to their students that they would have responsibility for solving the problem of climate change, they implied that the problem was solvable, but that for unspecified reasons, previous generations had failed to solve it. None explained that the problem gets harder to solve every year. None hinted that climate change might trigger state shifts in human society or the biosphere (Barnosky et al., 2012, 2011; Scheffer, 2009). None suggested that future generations might need to find "clumsy solutions" to a "wicked problem" (Hulme, 2009, p. 333). This optimism may explain the lack of attention to adaptation, and the tendency to look at climate change as a current problem in the Arctic, but as a future problem for Metro Atlanta. As I understand postcarbonism, you cannot separate *de facto* school segregation from suburban sprawl, or Metro Atlanta's growing heat island from climate change. Recycling can no more prevent the extinction of polar bears than Sherman's army could solve the problem of racism. If today's children survive the next 100 years, they will find no easy solutions to the problems of life in a world of changing norms and constant storms.

Implications: Teachers as Boundary Workers

As Akkerman and Bakker (2011) wrote, "All learning involves boundaries" (p. 132). They defined a boundary as "a sociocultural difference leading to a discontinuity in action or interaction" (p. 133). Schwartz (2014) argued that teachers and students are both boundary workers. Teachers help build bridges between two worlds, and students are asked to cross those bridges. Some students will cross the bridge between laypeople and scientists and live in the world of professional science, but most students will inhabit the world of adult laypeople, who sometimes seek to understand the world of professional science as citizens or interested observers.

Boundary work can be especially challenging, because boundary workers have to play dual roles (Williams, Corbin, & McNamara, 2007) and are held accountable by both communities (Fisher & Atkinson-Grosjean, 2002). Science teachers are accountable to multiple communities, including their students, their students' parents, their colleagues, the school administration, and the scientific community. In agreeing to participate in this study, the teachers became accountable to me, and I became accountable to them. As a science fan, in writing up the case reports, I pointed out small instances where I thought the teachers mistook the science. These were often passing comments, no longer than a single sentence; sometimes they were footnotes. During the member checking process, all of the teachers thanked me for pointing out their mistakes, and promised to do better the next time they taught the material. Thus it seems that the boundary between the scientific and the lay communities was especially salient for the teachers in this study. This is altogether fitting and proper, as a science teacher's job is to build a bridge between those two communities.

All of the teachers in this study occupy positions between the lay and scientific communities. David, with his Ph.D. in Geology and a decades-long interest in climate change could be considered a member of the scientific community, though, having studied structural geology, he cannot be considered a climatologist. Tom has engaged in climate research, and his contacts with the climate science community coupled with his abiding interest give him a remarkably high level of expertise, especially for someone who was trained as a lawyer before becoming a 6th grade science teacher. David and Tom are both climate literate enough to read articles from peer-reviewed journals. Jeff and Annette both studied biology as undergraduates, and have learned climate science so they can teach it at the high school level. Grace has a Master's degree in biology, and she learned climate science so she can teach it at the fourth grade level. Therefore, of the teachers in this case study, Grace comes closest to exemplifying the layperson.

In Grace's case report, I mentioned that she conflated ozone depletion and climate change, and said that this is “well-documented misconception”. After reading the report, she indicated that she would review the terms, and I responded with an long email that explained the conditions in the stratosphere are not normally considered part of the ‘climate’, but that both ozone depletion and climate change would be considered ‘atmospheric change’ if anyone ever used the phrase. I explained that ‘stratospheric cooling’, is related to both global warming and ozone depletion, and concluded by saying:

> So you weren't really wrong. It's just more complex than most people realize. The academic science educators who insist that global warming and the ozone hole are completely distinct are in fact wrong, and lay people may have an intuitive understanding that goes much deeper than academics, who often make meaningless distinctions.

In discussing Annette's belief that her daffodils have started to bloom earlier because of global climate change, I pointed out that it was more likely a result of Metro Atlanta's sprawling heat archipelago. Annette's belief could easily be framed as a misconception. But maybe suburban sprawl is related to greenhouse emissions, and maybe the growth of urban heat archipelagos all over the globe is an aspect of global climate change. Maybe the Earth is one interconnected system. Maybe you can't separate local, regional, and global climate change any more than you can separate tropospheric warming from stratospheric cooling. Maybe you can't separate changes in the social climate from changes in the atmospheric climate.

In adopting a postcarbonist frame for this study, I am suggesting that science teachers should take on a very difficult job. It is not enough to satisfy academic scientists by making exacting distinctions between ozone depletion and climate change or between urban heat islands and global warming. While making these distinctions, teachers also need to help their students understand the Earth as one complex and interconnected system. Plus they need to help their students understand: 1) how humans interact with this system, 2) how changes in the global environment feedback on human society, and 3) how these feedbacks might either reinforce or balance environmental changes. To accomplish this, I am proposing that science teachers help build a bridge between the natural sciences, the social sciences, and the emerging field of systems dynamics. In doing so, they need to be accountable to their students, their students' parents, their colleagues, the school administration, the scientific community, and to children yet unborn.

In short, I am proposing that science teachers take on an absurdly impossible task. I asked the teachers in this study how the University of Georgia might support them, and in the next section, I will share their thoughts.

Supporting Teachers

Science teachers need support if they are to meaningfully help young people adapt to life on a changing planet while mitigating the harm they may inflict on the planet and future generations. I asked the teachers in this study how the University of Georgia could support them in their efforts to teach climate change. The teachers had a lot of ideas, and certain themes recurred. They asked for workshops, teaching resources, and for trusted experts to recommend high-quality resources that have already been developed.

Workshops

Many teachers expressed a need for workshops that would help teachers gain mastery of the content, and provide a forum for them to share teaching strategies. All the teachers who spoke about workshops felt they should be short in length–ranging from a few hours to a few days–and close to home or school. Instead of hosting workshops at big university campuses, presenters could travel to schools, district science centers, or local colleges and universities. If K-12 schools hosted the workshops, the workshop leader(s) could speak to classes during the day, and work with teachers after school.

Annette pointed out that many environmental science teachers are trained in biology, and lack the needed background to teach about the physical environment. In particular, she said that all of the environmental science teachers she's talked to want training in meteorology, and that many also lack training in oceanography and human geography.

Teaching Resources

The teachers in this study voiced a need for a range of resources that could be used with their students. These included labs, videos, reading materials, and resources tailored for use in Georgia.

Labs.

Most of the teachers voiced a desire for hands-on activities or labs that students could do related to climate change. Jeff specifically wanted activities that would be "kinesthetic" and suggested that students might be able to "put something outside […] and go look at it [over several] weeks". He emphasized that such labs don't only need to connect to atmospheric science, but could connect to other disciplines, including oceanography and ecology. Many schools lack budgets for scientific equipment, and Grace recommended activities that could be done using low-cost materials such as paper-towel rolls. Alternately, the materials could be provided in kits that teachers could easily borrow.

Videos.

All of the teachers mentioned videos, but none of them thought the videos should be too long or unconnected to other teaching resources. Tom saw videos as potential scaffolding for reading and other activities, and Grace saw them as a way to capture student interest, and to provide scaffolding for teachers who may not be deeply knowledgeable about climate change. Jeff wanted a video that would help students make sense of the social and political controversy around climate change. In particular, he wanted to help students understand how people can "take the same data and make it mean different things". Annette and David both mentioned virtual guest lectures, in which university professors or other experts would put together age-appropriate presentations, which students could watch during class. David recommended coupling such presentations with activities for the students to do, and said that the materials could be put into a kit ("a podcast in a box") and distributed to classrooms. The science center staff has a lot of experience working in K-12 classrooms, and he felt that science center staff could work with professors to refine their lessons. The ideal person would have credibility and look good on camera. David said:

> Dr. Shepherd would be very credible–you know he's a great speaker and I don't know how much K-12 experience he has. But with a team that helps him [refine a lesson] and [film] it where he is face to face with kids […]. That would be great.

Reading materials.

Tom wanted age-appropriate readings that could help young people keep up-to-date on changes in climate science. Students can read emails, and Tom recommended a program called "Astro Buddies" in which a number of astronomy professors made their email addresses available to students who were studying astronomy. The students can email questions to the astronomers, who were very good at answering the questions using age-appropriate language. If a particular answer isn't clear to the students, the email format allowed the students to ask for clarification. It might be quite easy to start developing a similar program with climate scientists.

Locally relevant.

A number of teachers asked for locally relevant materials for teaching about climate change. David recommended looking at how climate change might impact farmers and coastal communities. Annette recommended materials related to bloom times and the water cycle, as well as data related to greenhouse gas emissions. Annette didn't think that huge amounts of data would be needed, and that students could do some simple data analysis and graphing as a learning activity. I have talked with an elementary school teacher who wanted to use phenology data with her second grade students, so such data sets might be useful for teachers who work with a range of ages. The greatest challenge might be creating an intuitive user-interface, and coming up with several well-tested activities for students to do with the data. Jeff specifically wanted the students to be able to analyze data sets that wouldn't lead them to one preset conclusion. Jeff's desire for nuance might be met by asking student to analyze temperature data from Metro Atlanta, while encouraging them to investigate urban heat islands as an aspect of climate change. Absent a discussion of urban heat islands, the phenological data Annette asked for could easily be misinterpreted.

Recommended Resources

While some of the teachers' ideas would be hard to implement, one idea was fairly easy. There is already a lot of material about climate change on the internet, but it is sometimes hard for teachers to find high quality materials. The teachers in this study considered the University of Georgia to be a trustworthy source of information, and if the University were to recommend resources for climate change education, Georgia teachers would be likely to use them. Grace thought that teachers would appreciate links to "approved videos". She said the videos would need to be "pretty short" and it would be helpful to organize them into categories based on the appropriate age group. There could also be videos for teachers to learn more about climate change. David pointed out, "People should know that Realclimate[.org] and SkepticalScience[.com] are good places to start if you get stuck on something".

Further Research

This research suggests many avenues for continued work. I was very lucky to observe a number of excellent teachers, and other teachers might build on their outstanding work. This case study was conducted as an instrument to understand climate change education, but other cases might be more intrinsically interesting. Some of the resources that the teachers requested could be provided, and I will highlight two of these. Finally, the University of Georgia might research one strategy to help Georgia's youth adapt to climate change.

Share Current Best Practices

I had the opportunity to witness some exceptionally high quality teaching. In particular, the two teachers at the science center have refined their lessons by teaching them over and over in diverse settings. David felt that the science center was a "tremendous" though "underutilized" resource, and he imagined it becoming a resource not just for the district, but for the nation. "We develop curriculum all the time, stuff that we developed to use ourselves could be spread out more. […] The limit is just how long is the day and what can we get done". The science center is under financial strain because of funding cuts from the district, and if the University of Georgia were to partner with the science center in writing a grant, it could provide an alternative income for the center while making a valuable resource available to the larger community. GEMS, a project at the Lawrence Hall of Science, has a lot of experience transforming lessons that were designed for use in a science center for classroom use, and might prove another partner. David has expressed a desire to help transform his lessons, so they could be more widely distributed. He will soon retire, and might volunteer his time for a pilot project. IRB restrictions require that I destroy my videotapes upon completion of this research, but if people want to continue with this aspect of the work, I could amend the IRB.

Tom's Project Based Learning unit was simply excellent. He has been refining the unit for close to a decade, and he is already sharing it with the other sixth grade science teachers at his school. I suspect that his other units are equally good. In hindsight, I should not have been surprised at Tom’s awesomeness, since he has been recognized as the outstanding Earth science teacher in the region. Several national organizations already identify outstanding teachers, and it might be worthwhile to document, refine, and publish teacher guides based on what these outstanding teachers are already doing. Again, I have videotapes of Tom's climate change unit, and he might be willing to partner with the University in a pilot project that would make his PBL widely available, and having done this, it might be possible to get grant support to document and share the best practices of outstanding teachers. The National Association of Geoscience Teachers might prove a good partner in such an effort.

Intrinsic Case Studies

This was an instrumental case study to understand climate change education within Metro Atlanta K-12 science classrooms. Other cases might be more intrinsically interesting, like climate change education in small island nations, the arctic, or low-lying communities. Given my conviction that you can't separate the natural from the human world, it would be interesting to observe interdisciplinary teams of teachers who collaborate to teach about climate change across the curriculum. Jeff was far from being a climate skeptic, but because of his willingness to listen to the skeptic's arguments, I found his case the most challenging, and therefore the most personally interesting. Finding true climate skeptics and documenting their teaching practices and the thinking behind their practice might be interesting, while providing insight that might help forestall the next evolution debate.

Curriculum Development

As discussed earlier, the teachers spoke about a number of ways that the University of Georgia could support their efforts to teach climate change. Many of the teachers voiced a desire for materials that focused on climate change in Georgia, and much of what they requested could be put together with relative ease.

Jeff requested materials on oceanography, and I found very few materials on teaching about ocean acidification. In particular, the lessons I found all seemed to deal either with ocean chemistry or biology, and I have ideas on how to combine biology and chemistry, using a fairly simple setup.

Adaptation

I have suggested that Metro Atlanta's schools could investigate ways to mitigate and adapt to local climate change. Researchers at the University of Georgia could take the lead in investigating this question, and University administrators could take the lead in instituting reforms. Given that heat waves are the single greatest cause of weather-related mortality, and the fact that urban heat islands become even more intense during heat waves, I might start by investigating whether August is the ideal time to require Metro Atlanta's students to return to school. An examination of energy consumption and student health records coupled with weather and climate data might provide useful information. Interviews and surveys of students and faculty might also provide useful data.

100 Years

Few remember his name, but on June 24, 1914, Nedeljko Čabrinović learned that the Archduke Franz Ferdinand would be visiting Sarajevo on June 28. Nedeljko had tuberculosis, and knowing that he would soon die anyway, he contacted several of his friends, and they conspired to murder the Archduke, who they felt was oppressing their people. No one alive 100 years ago could imagine gas attacks, aerial bombardments, or the stinking horrors of trench warfare. Auschwitz was an empty field in the middle of Poland, and Hiroshima was a small delta city, known for its schools and shopping centers. How could anyone raised in the 19th century possibly prepare children for the 20th century?

I suspect the 21st century will bring even greater challenges than the last century did. If human eyes greet the dawn on June 24, 2114, that day will quickly pass into history, only to be erased from memory when humanity's candle burns out. I do not know how to live within the absurdity of time. I do not know how to prepare children to face an unfathomable future. I only know that they will not get a second chance on Earth.

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APPENDIX A

GEORGIA PERFORMANCE STANDARDS (GPS) RELATED TO CLIMATE SCIENCE

This Appendix contains three separate tables:

A1) GPS that offer explicit encouragement to teach climate science

A2) GPS that provide openings to teach climate science

A3) GPS offer either explicit or implicit encouragement to teach climate change denial.

I offer three observations:

1) There is no explicit mention of climate change until high school.

2) Given the complexity of climate science, and its numerous connections to the rest of the scientific enterprise, there are no doubt openings that I haven't identified.

3) As I read them, the Meteorology standards encourage the teaching of climate science as controversial.

TABLE A1

GPS that offer explicit encouragement to teach climate science

Standard Number	Text	Comments
High School Earth Science		
SES5: e, f	Students will investigate the interaction of insolation and Earth systems to produce weather and climate. e. Describe the hazards associated with extreme weather events and climate change (e.g., hurricanes, tornadoes, El Niño/La Niña, global warming). f. Relate changes in global climate to variation in Earth/Sun relationships and to natural and anthropogenic modification of atmospheric composition.	Some teachers might read the references to changes in insolation and natural modification of the atmosphere as invitations to discuss climate change denial.
SES6: c	Students will explain how life on Earth responds to and shapes Earth systems. c. Explain how geological and ecological processes interact through time to cycle matter and energy, and how human activity alters the rates of these processes (e.g., fossil fuel formation and combustion).	
High School Environmental Science		
SEV4: e	Students will understand and describe availability, allocation and conservation of energy and other resources. e. Describe the commonly used fuels (e.g. fossil fuels, nuclear fuels, etc.) and some alternative fuels (e.g. wind, solar, ethanol, etc.) including the required technology, availability, pollution problems and implementation problems. Recognize the origin of fossil fuels and the problems associated with our dependence on this energy source. f. Describe the need for informed decision making of resource utilization. (i.e. energy and water usage allocation, conservation, food and land, and long-term depletion)	

SEV5: c, e	Students will recognize that human beings are part of the global ecosystem and will evaluate the effects of human activities and technology on ecosystems. c. Explain how human activities affect global and local sustainability. e. Describe the effects and potential implications of pollution and resource depletion on the environment at the local and global levels (e.g. air and water pollution, solid waste disposal, depletion of the stratospheric ozone, global warming, and land uses).	Global warming is offered as an example of what might be discussed in the context of "potential implications". Climate change isn't required.
High School Geology		
SG4: f	Students will evaluate how climate systems affect landforms on the surface of the Earth. f. Discuss how changes in greenhouse gases have affected Earth's climate history.	While it frames climate change as "history", it explicitly connects of greenhouse gases and climate. Another Geology standard frames climate change as controversial.
High School Oceanography		
SO3: d	Students will analyze how weather and climate are influenced by the oceans. d. Explain relationships between climate change, the greenhouse effect, and the consequences of global warming on the ocean.	
SO4: e	Students will investigate waves and tides and analyze their influence on coastal processes. e. Identify natural hazards (e.g., tsunamis, hurricanes, and sea level change) and their impact on coastal communities.	Some might not consider this explicit, but the only reason sea level change might impact coastal communities would be if it rises as a result of climate change.
High School Ecology		

SEC5: a, b, c	Students will assess the impact of human activities on the natural world, and research how ecological theory can address current issues facing our society, locally and globally. a. Describe the sources, environmental impacts, and mitigation measures for major primary and secondary pollutants. b. Compare and contrast the ecological impact of sustainable and non-sustainable use of resources, including soil, timber, fish and wild game, mineral resources, and nonrenewable energy. c. Evaluate the causes and impacts on ecosystems of natural and anthropogenic climate change.	Human impact. The mention of natural climate change may be seen as an opening to climate change deniers.

TABLE A2

GPS that provide openings to teach climate science

Standard Number	Text	Comments
First grade		
S1E1	Students will observe, measure, and communicate weather data to see patterns in weather and climate.	Climate is mentioned.
Fourth Grade		
S4E4: d	Students will analyze weather charts/maps and collect weather data to predict weather events and infer patterns and seasonal changes. d. Differentiate between weather and climate.	The difference between climate and weather addresses a major misconception related to climate change.
Sixth Grade Earth Science		
S6E4	Students will understand how the distribution of land and oceans affects climate and weather.	Climate is mentioned.
S6E6	Students will describe various sources of energy and with their uses and conservation.	Discussing alternative energy could be an opening to the problems with fossil fuels.
Seventh Grade Life Science		
S7L4: a, c	Students will examine the dependence of organisms on one another and their environments. a. Demonstrate in a food web that matter is transferred from one organism to another and can recycle between organisms and their environments. c. Recognize that changes in environmental conditions can affect the survival of both individuals and entire species.	Discussing the carbon cycle could the importance of the environment for all living things could lead to a discussion of climate change.

High School Earth Science		
SES1: a	Students will investigate the composition and formation of Earth systems, including the Earth's relationship to the solar system. e. Identify the transformations and major reservoirs that make up the rock cycle, hydrologic cycle, carbon cycle, and other important geochemical cycles.	Explicit mention of carbon cycle.
SES4: e	Students will understand how rock relationships and fossils are used to reconstruct the Earth's past. e. Use geologic maps and stratigraphic relationships to interpret major events in Earth history (e.g., mass extinction, major climatic change, tectonic events).	Opening to discuss paleoclimates.
High School Environmental Science		
SEV1: a	Students will investigate the flow of energy and cycling of matter within an ecosystem and relate these phenomena to human society. a. Interpret biogeochemical cycles including hydrologic, nitrogen, phosphorus, oxygen, and carbon cycles. Recognize that energy is not recycled in ecosystems.	Carbon Cycle.
SEV2: a	Students will demonstrate an understanding that the Earth is one interconnected system. a. Describe how the abiotic components (water, air, and energy) affect the biosphere.	
SEV3: a	Students will describe stability and change in ecosystems. a. Describe interconnections between abiotic and biotic factors, including normal cyclic fluctuations and changes associated with climatic change (i.e. ice ages).	Although it explicitly mentions climate change, note that it focuses on "normal cyclic fluctuations" and says (i.e. ice ages) not (e.g. ice ages).

SEV4: c, d, f	Students will understand and describe availability, allocation and conservation of energy and other resources c. Describe how energy and other resource utilization impact the environment and recognize that individuals as well as larger entities (businesses, governments, etc.) have impact on energy efficiency. d. Describe the relationship of energy consumption and the living standards of societies. f. Describe how political, legal, social, and economic decisions may affect global and local ecosystems.	
High School Ecology		
SEC2: b	Students will investigate factors influencing population density, dispersion, and demographics. d. Relate the rapid growth of human population to environmental problems.	Human impact on environment.
SEC4: a	Students will analyze biogeochemical cycles and the flow of energy in ecosystems. a. Compare and contrast the carbon, water, oxygen, phosphorus, nitrogen, and sulfur cycles, describing their flow through biotic and abiotic pools, including human influences.	Carbon cycle.

TABLE A3

GPS that explicitly or implicitly encourage teaching climate science as controversial.

Standard Number	Text	Comments
High School Geology		
SG5: c	Students will apply geologic knowledge to the use of resources in the Earth and the control of human impacts on Earth's systems. c. Research current controversies regarding the extraction and use of geologic resources (e.g. causes of global warming, drilling for oil, safety and environmental impact of mining).	Climate change is framed as controversial.
High School Meteorology		
SM5: c, d, e, f	SM5. Students will differentiate the climates of Earth, how climate changes through time, and the theories regarding current climate change. c. Evaluate the effects of El Nino-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) on climate. d. Analyze current methods of climate prediction. (Predictions of ENSO, NAO, long-range outlooks, etc.) e. Explore radiative equilibrium and demonstrate the differences between the greenhouse effect and global warming. f. Judge the current theories explaining global warming and argue the potential implications of global warming on global weather patterns and severe weather events.	It explicitly states that students should learn "theories" not "theory". c) & d) ENSO and NAO are weather phenomena. Climate change deniers argue that ENSO and NAO explain observed long term changes in climate. f) Framed as "theories" to be argued.

APPENDIX B

DATA COLLECTION INSTRUMENTS

APPENDIX B1

Interview Guide

Questions in bold make up the formal interview guide. The others are possible follow-ups. Each of the questions aims to inform one or more of the research questions:

1) What do teachers teach about climate change?

2) How do teachers teach about climate change?

3) What resources do teachers use in teaching and learning about climate change?

4) What institutional factors do teachers say influence their decisions on what and how to teach about climate change?

5) What sociocultural challenges and supports do they relate in their efforts to teach climate change?

Interview #1: Before teaching about climate change

Try to remember a class that has gone well this year? What was it like?

What did you do? How did the kids react? What went well about it?

How would you describe this school to someone who has never been here? (RQ 5)

What are the kids like? What are your colleagues like? How about other staff? How about the administration? How about the parents?

How would you describe the larger community to someone who has never been here? (RQ 5)

Do you live here? If not, how does it differ from your home community?

What do you hope your students will learn as a result of your lessons on climate change? (RQ 1)

What factors influenced your decisions about what students should learn about climate change? (RQ's 3/4/5)

How have the standards influenced your decisions? How has the school administration influenced your decisions? How has the school culture influenced your decisions?

How have you learned about climate change? (RQ 3)

What resources are you using to continue learning about climate change?

Interview #2: During the climate change unit

Think back on the most recent class that I observed. How did it go? (RQ's 1/2/4/5)

What standards were you trying to teach? How did the kids react? What went well? What would you change if you taught it in the future? Did you enjoy teaching it? What was fun? What was frustrating?

What resources did you use in preparing the class? (RQ 3)

Interview #3: After the climate change unit

How do you think the climate change unit went? (RQ's 3/5)

How did the kids react? What went well? What would you change if you taught it in the future? Did you enjoy teaching it? What was fun? What was frustrating?

Do you feel that your students supported your decisions about how to teach climate change? (RQ 5)

How did they show this? How did this influence you?

Do you feel that their parents supported your decisions about how to teach climate change? (RQ 5)

How did they show this? How did this influence you?

Do you feel that your colleagues support your decisions about how to teach climate change? (RQ's 4/5)

How do they show this? How does this influence you?

Do you feel that your administration supports your decisions about how to teach climate change? (RQ's 4/5)

How do they show this? How does this influence you?

How could the University of Georgia support you in your efforts to teach climate change? (RQ's 3/5)

Would you like courses? How about classroom visits from Professors? Access to Professors or graduate students for questions? Lesson plans and kits?

APPENDIX B2

Classroom Observation Guide

Before class begins:

Engage in light conversation with the teacher. Inform him or her of the fact that I will be using my word-processor to keep notes, and that I would be happy to provide a copy if he or she requests it. If so, invite corrections or feedback on the notes. Ask if he or she has any questions.

Sketch the classroom taking care to note the student seating arrangements, location of the teachers desk, any lab equipment, work spaces, etc. Note anything that may be posted or written on the board.

During class:

Note how many students are present.

Note where they seat themselves on the classroom sketch.

Note where the teacher places him/herself at the start of class, and note how much the teacher moves during class.

Note what time class starts, and the timing of any major shifts (such as the introduction of a new learning activity, or new topic).

If the class rearranges itself (for instance to do a lab or engage in small group activities) note the new arrangement.

Observational notes should focus on teacher behaviors:

- What does the teacher communicate to the students about climate change?
- How does the teacher communicate this?
- How does the teacher respond to student questions?
- How does the teacher engage the students in their learning?
- What questions does the teacher ask the students to think about?
- What learning activities do the students engage in to aid their learning?

Note: Do not record individually identifiable information about students, including their gender, race, hairstyle, or dress. In those rare cases where it seems important to note the behavior of individual students, identify them as “Student A”, “Student B”, etc.

After class:

Make light conversation with the teacher, and finalize any plans for the next visit, interview, etc..

APPENDIX B3

Matrix of Data Sources and Research Questions

TABLE B3.1
Interview Questions

Research Question	**Interview Questions**[39]
1) What do teachers teach about climate change?	1) What do you hope your students will learn as a result of your lessons on climate change? 2) Think back on the most recent class that I observed. How did it go?
2) How do teachers teach about climate change?	2) Think back on the most recent class that I observed. How did it go?
3) What resources do teachers use in teaching and learning about climate change?	1) What factors influenced your decisions about what students should learn about climate change? 1) How have you learned about climate change? 2) What resources did you use in preparing the class? 3) How do you think the climate change instruction went? 3) How could the University of Georgia support you in your efforts to teach climate change?
4) What institutional factors do teachers say influence their decisions on what and how to teach about climate change?	1) What factors influenced your decisions about what students should learn about climate change? 2) Think back on the most recent class that I observed. How did it go? 3) Do you feel that your colleagues support your decisions about how to teach climate change? 3) Do you feel that your administration supports your decisions about how to teach climate change?
5) What sociocultural challenges and supports do they relate in their efforts to teach climate change?	1) How would you describe this school to someone who has never been here? 1) How would you describe the larger community to someone who has never been here?

[39] The number proceeding each question identifies each of the three interviews: 1) Pre-observation, 2) Day of observation, 3) After observation(s).

	1) What factors influenced your decisions about what students should learn about climate change? 2) Think back on the most recent class that I observed. How did it go? 3) How do you think the climate change instruction went? 3) Do you feel that your students supported your decisions about how to teach climate change? 3) Do you feel that their parents supported your decisions about how to teach climate change? 3) Do you feel that your colleagues support your decisions about how to teach climate change? 3) Do you feel that your administration supports your decisions about how to teach climate change? 3) How could the University of Georgia support you in your efforts to teach climate change?

TABLE B3.2
Other Data Sources

Research Question (Research Question 5 will be informed by interviews.)	**Data Sources**
1) What do teachers teach about climate change?	Lesson plans. Artifacts of instruction. Classroom observations.
2) How do teachers teach about climate change?	Lesson plans. Artifacts of instruction. Classroom observations.
3) What resources do teachers use in teaching and learning about climate change?	Examine the resources, if possible. If not possible, follow-up questions during the interview.
4) What institutional factors do teachers say influence their decisions on what and how to teach about climate change?	Current local and national standards. Local and national NGSS. Relevant documents generated by schools and districts.

APPENDIX B4

UNIVERSITY OF GEORGIA
CONSENT FORM
A COLLECTIVE CASE STUDY OF CLIMATE CHANGE EDUCATION IN GEORGIA

Researcher's Statement
I am/We are asking you to take part in a research study. Before you decide to participate in this study, it is important that you understand why the research is being done and what it will involve. This form is designed to give you the information about the study so you can decide whether to be in the study or not. Please take the time to read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, you can decide if you want to be in the study or not. This process is called "informed consent." A copy of this form will be given to you.

Principal Investigator: David Jackson
Department of Math and Science Education
706-542-1763
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Leonard Bloch
Department of Math and Science Education
720-878-5502
lenbloch@uga.edu

Purpose of the Study
The purpose of the study is to learn about teachers' practices teaching climate change and how the University of Georgia can best support teachers in their efforts. We have asked you to participate because you teach about climate change.

Study Procedures
If you agree to participate, you will be asked to …

1) Answer questions about your teaching practices and the reasons for them, which will take about one hour. All interviews will be audio-recorded the recording will be deleted within thirty days of the completion of the research.
2) Allow a researcher to observe you teaching about climate change. With your consent, the classes will be videotaped. We will ask to observe between one and six class periods.
3) Answer questions about one of the lessons you teach about climate change, which will take about one hour.
4) Answer questions about the level of community support for your teaching decisions around climate change, which will take about one hour.

Risks and discomforts
We do not anticipate any risks from participating in this research.

Benefits
Potential benefits for you are that some participants will enjoy the opportunity to be heard, and to reflect on their own practice. I will share the results of my research with the participants, and they will have the opportunity to learn how other teachers approach climate change education. This will be especially important in ligh of the fact that the upcoming *Next Generation Science Standards* will emphasize climate change, and teachers will be expected to devote more time to it in coming years. Furthermore, you may have the opportunity to benefit from any new supports the University provides teachers as a result of this research.

Potential benefits to society/humankind include that students may be better prepared to face the challenges of climate change and they may participate in the wider mitigation/adaptation efforts.

Audio/Video Recording
With your permission, each of the three interviews will be recorded, so they can later be transcribed. After transcription, the recordings will be archived for reference, and will be deleted upon completion of the research.

Please provide initials below if you agree to have the **interviews *audio* recorded or not.** You may still participate in this study even if you are not willing to have the interview recorded.

_______I do not want to have the interviews recorded.
_______I am willing to have the interviews recorded.

With your permission, each of the classroom observations will be video recorded. The video camera will be focused on you, the teacher, and the camera will be positioned in the back of the room, so as not to record the faces of the students. Data analysis will focus on your actions as a teacher, and no specific mention of student behaviors will be included within the research report. The video recordings will be referred to during data analysis, and will be deleted upon completion of the research.

Please provide initials below if you agree to have the **classroom observations *video* recorded or not**. You may still participate in this study even if you are not willing to have the interview recorded.

_______I do not want to have the classroom observations recorded.
_______I am willing to have the classroom observations recorded.

Privacy/Confidentiality
We will endeavor to maintain confidentiality. You will be assigned a pseudonym and this will be used on all interview transcripts and other data instruments. Researchers will not release identifiable results of the study to anyone other than individuals working on the project without your written consent unless required by law.

Taking part is voluntary
Your involvement in the study is voluntary, and you may choose not to participate or to stop at any time without penalty or loss of benefits to which you are otherwise entitled. If you decide to withdraw from the study, the information that can be identified as yours will be kept as part of the study and may continue to be analyzed, unless you make a written request to remove, return, or destroy the information.

If you have questions
The main researchers conducting this study are David Jackson, a professor at the University of Georgia, and Leonard Bloch, a graduate student at the University of Georgia. Please ask any questions you have now. If you have questions later, you may contact **David Jackson** at **djackson@uga.edu** or at **706-542-1763**, or you may contact **Leonard Bloch** at **lenbloch@uga.edu** or at **720-878-5502**. If you have any questions or concerns regarding your rights as a research participant in this study, you may contact the **Institutional Review Board (IRB) Chairperson** at **706-542-3199** or **irb@uga.edu**.

Research Subject's Consent to Participate in Research:
To voluntarily agree to take part in this study, you must sign on the line below. Your signature below indicates that you have read or had read to you this entire consent form, and have had all of your questions answered.

_____________________________ ___________________________ __________

Name of Researcher Signature Date

_____________________________ ___________________________ ___________

Name of Participant Signature Date

Please sign both copies, keep one and return one to the researcher.

APPENDIX C

MATERIALS ASSOCIATED WITH DAVID WOOLF

Appendix C1

Handout used in David Woolf's Geology Class

[redacted] Our carbon future p. 15
11/6/13

Name ____

Rough calculations of the future from SOCCR Carbon Cycle Diagram

Refer to the laminated carbon cycle diagram on your table in the lab.

Black print represents natural processes.

Red print shows human influences.

[Numbers in braces] are storage of carbon, in billions of tons (Gt).

→ Numbers with arrows are movements of carbon, in Gt **per year**.

1. Write the correct order, from the least to the most carbon, for the following locations where Earth's carbon is stored: biosphere, atmosphere, solid Earth, hydrosphere.

2. How much total carbon has been added by humans to the atmosphere? to the hydrosphere?

3. How much fossil fuel carbon is being taken from the Earth each year? (hint: subtract 0.1 from the value of "Fossil-Fuel and Cement Emissions.")

Fossil fuels that can be extracted with a similar degree of effort to that used today are called "conventional." "Conventional reserves" are scientists' best estimates of how much may remain.

4. How much carbon is left in the Earth in "conventional reserves" of coal, oil, and gas (add them together)?

5. At the present rate (see question #3), how long will it take to use up all of the "conventional reserves" of coal, oil, and gas?

6. Suppose only one-half of the total carbon now remaining in "conventional reserves" is added to the 777 Gt now in the atmosphere? What will be the total Gt of carbon in the atmosphere then?

7. Assuming each Gt of carbon in the atmosphere equates to .49 parts per million (ppm) of CO2, how would the above answer convert to ppm?

8. Explain the following statement: The risk of continuing to burn fossil fuels may not be in running out of them, but rather in not running out of fossil fuels soon enough.

Appendix C2

First page of handout used in David Woolf's AP Environmental Science Class

Name ___________________________ Period________________________ Date______________________

Matching pictures from "Can Coal be Clean?" with some of the supporting concepts of the

EARTH SCIENCE LITERACY INITIATIVE

The Big Ideas and Supporting Concepts of Earth Science

BIG IDEA 1. Earth scientists use repeatable observations and testable ideas to understand and explain our planet.

_ _ **Earth scientists find solutions to society's needs.** Earth scientists work on challenging problems that face humanity on topics such as climate change and human impacts on Earth. Earth scientists successfully predict hazards to humans and locate and recover natural resources, making possible the flourishing of humans on Earth. (1.1)

BIG IDEA 3. Earth is a complex system of interacting rock, water, air, and life.

___ **All Earth processes are the result of energy flowing and mass cycling within and between Earth's systems.** This energy is derived from the sun and Earth's interior. The flowing energy and cycling matter cause chemical and physical changes in Earth's materials and living organisms. For example, large amounts of carbon continually cycle among systems of rock, water, air, organisms, and fossil fuels such as coal and oil. (3.2)

___ **Earth exchanges mass and energy with the rest of the Solar System.** Earth gains and loses energy through incoming solar radiation, heat loss to space, and gravitational forces from the sun, moon, and planets. Earth gains mass from the impacts of meteoroids and comets and loses mass by the escape of gases into space. (3.3)

BIG IDEA 7. Humans depend on Earth for resources.

_ _ **Resources are distributed unevenly around the planet.** Resource distribution is a result of how and where geologic processes have occurred in the past, and has extremely important social, economic, and political implications. (7.4)

___ **Fossil fuels and uranium currently provide most of our energy resources.** Fossil fuels, such as coal, oil, and natural gas, take tens to hundreds of millions of years to form. Their abundance will make them the dominant source of energy for the near future. New sources, such as methane hydrates, are being explored. (7.9)

BIG IDEA 9. Humans significantly alter the Earth.

___ **Earth scientists use the geologic record to distinguish between natural and human influences on Earth's systems.** Evidence for natural and human influences on Earth processes is found in ice cores and soils, and in lake, estuary, and ocean sediments.(9.2)

_ _ **Humans cause global climate change through fossil fuel combustion, land-use changes, agricultural practices, and industrial processes.** Consequences of global climate change include melting glaciers and permafrost, rising sea levels, shifting precipitation patterns, increased forest fires, more extreme weather, and the disruption of global ecosystems. (9.3)

_ _ **Human activities alter the natural land surface.** Humans use more than one-third of the land's surface not covered with ice to raise or grow their food. Large areas of land, including delicate ecosystems such as wetlands, are transformed by human land development. These land surface changes impact many Earth processes such as groundwater replenishment and weather patterns. (9.5)

Note: ___ blanks are for the first four pictures that appear in the slide show (abcg)
while _ _ blanks are for the last four pictures (defh)

APPENDIX D

MATERIALS ASSOCIATED WITH JEFF ZALE

Appendix D1

Handouts and Rubric for Jeff Zale's Global Warming One Pager

a) Handout for class discussion

Main Idea	Supporting Details
How do scientists define "global warming?" Compare and contrast GW and global climate change.	
How is GW similar to the greenhouse effect? How is GW different from the greenhouse effect?	
How can the oceans influence GW? How can GW influence the oceans?	

APPENDIX D1

b) Assignment

Global Warming One-Pager

SO3. Students will analyze how weather and climate are influenced by the oceans.

d. Explain relationships between climate change, the greenhouse effect, and the consequences of global warming on the ocean.

A one-pager is a strategy for summarizing and responding to information from a reading. Your one-pager will be used as a guide during our class discussion regarding the topic.

Your one-pager should include:

1. At least THREE visual images, symbols, or representations of an idea/concept that is especially important to your group from the research. Use color to further enhance symbolic meanings and you may find photographs, magazine clippings, or other sources that will increase the visual impact of your work. These images should explain your team's understandings of the influences global climate change and the oceans have on each other. You should also include graphics that support your team's position.

2. At least THREE direct quotes or facts from your research that are NOT opinion but rather based on data. The selected information should support your group's understanding. They may show important ideas or give important data that supports your team's understanding. Be sure to use quotation marks. Be sure to include the source of your data (the agency, the researcher, and so forth- a website is NOT a source, it's a link to the source)

3. At least ONE question. Many times we wish we had more data or that someone or some agency would do more research in a certain area. Identify an area where more research should be done to make the concept of global warming easier to understand. What question do you want answered? The question should be something that is realistic.

4. ONE global warming summary section. In this section you:
    a. Describe how global warming is different from the greenhouse effect.
    b. Explain how the oceans influence global warming (either how they may enhance it, mask it or moderate it).
    c. Explain how global warming influences the oceans.

APPENDIX D1

c) Rubric for assignment

ONE PAGER RUBRIC

GROUP MEMBERS: ________________________________

____

____

____

I. 3 Visual images, symbols or representations (9 pts total) _________

A) Supports/exemplifies relationship of GW to oceans
B) Legible, orderly, clear, good size
C) Variety, color

II. 3 Direct quotes (3 pts. each) _________

A) Data v. opinion
B) Supports/explains relationship of GW and oceans
C) Provides source, in quotations

III. 1 Question about your topic (3 pts) __________

A) Realistic
B) Cannot be easily answered unless research is undertaken
C) High-level question (not yes/no); requires experimentation/investigation

IV. Summary Section (15 pts) __________

A) GW v. Greenhouse
B) Influence OF oceans on GW
C) Influence ON oceans by GW

V. Group understanding/contributions (4 pts) __________

A) All are accountable/equitable (effort is equal)
B) All are knowledgeable (I will verbally quiz all in the group regarding any information on the one-pager.)

TOTAL: _______/ 40

Appendix D2

Handout used for Jeff Zale's Lab Activity

Sea Ice Lab

Lesson Focus: Sea Ice

Learning Goals:

- Assess the influence of ice on the heating rates of water
- Compare heating rates of fresh and salt water

Procedure:

1. Obtain a 600 ml beaker, a hot plate, stirring rod and a thermometer. Your teacher will assign you to particular "environmental condition."
2. Place the determined amount of ice in the beaker. Then fill the beaker with the directed type of water (salt or fresh) so that the water/ice mixture is as close to 400 ml as possible. Note the initial volume as exact as you possibly can; record this value. Use the grease pencil provided to mark the location of the surface in your beaker.
3. Record the initial temperature in your data table.
4. Next predict what the final temperature of the mixture will by the end of the heating period. Record this value on the data table.
5. Begin heating your ice/water mixture. Set your hot plate heating value on level HIGH. Use the stirring rod to GENTLY but consistently stir the mixture during the heating process.
6. CAUTION: Use care when working with hot materials and hot equipment.
7. Mark the time in your data table at which the ice is totally melted; record this as the number of minutes it took to completely melt the ice. Record the temperature at that moment.
8. Continue heating your water for as long as it took to melt the ice (so if it took 7 minutes for all the ice to melt, continue heating the water for seven more minutes).
9. When the heating time is complete, record the temperature and turn the hot plate to the OFF position but leave the thermometer in the beaker and leave the beaker on the hot plate. Do NOT touch the beaker. Continue observing the temperature of the water and record the highest temperature your thermometer reaches.
10. Also, observe the volume in the beaker as accurately as possible; use the grease pencil marking as a reference. Record this value as the final volume.
11. Upon the completion of the heating process, allow time for the heated water to cool and then dispose of the water in the sink.
12. Return materials as directed by your teacher.

Data:

Scenario	**Great Lakes** (100 ml ice + 300 ml tap water)	**Arctic Lake** (200 ml ice + 200 ml tap water)	**North Atlantic** (100 ml ice + 300 ml salt water)	**Arctic Ocean** (200 ml ice + 200 ml salt water)
Exact Initial Volume (mL)				
Initial temp with ice (^{0}C)				
Initial Time when heating begins				
Predicted Final Temp (^{0}C)				
Minutes needed to melt ice (min)				
Temp of complete ice melt (^{0}C)				
Temp when heating time is complete (^{0}C)				
Exact final volume (mL)				
Highest temp attained after heating (^{0}C)				
Rate of heating with ice (^{0}C/min)				
Rate of heating without ice (^{0}C/min)				

Calculations:

A. To calculate the rate of heating with ice, divide the total temperature change when the ice was present by the time it took for the ice to melt. Answer should be in degrees per minute.
B. To calculate the rate of heating without ice, divide the total temperature change when NO ice was present by the time the water was heated when no ice was present. Answer should be in degrees per minute.

Questions:

1. Examine your data and calculations; compare the rate (degrees/min) at which temperature increased when ice was present and when no ice was present. The hot plate was on the same setting the entire investigation so why might the two values differ?

2. Class data is posted on the board. Copy the average for each category that your group did not investigate onto your data table. Examine just the beakers that contained fresh water. What relationship, if any, is there between the amount of ice present in the fresh water and the rate of temperature change (degrees/minute)?

3. Next examine just the beakers containing salt water and ice. What relationship, if any, is there between the amount of ice present in the saltwater and the rate of temperature change (degrees/minute)?

4. Compare a salt water condition to a similar fresh water condition. What relationship, if any, is there between the type of water in the mixture and the rate of temperature change (degrees/minute)?

5. Overall, what effect does "sea" ice have on the rate at which ocean temperatures change?

6. How might glaciers, ice packs and sea ice influence the climate for our planet?

7. What might be a likely outcome if the **amount** of ice on our planet was reduced?

8. Does the **rate** at which the amount of ice on our planet is reduced have an influence on overall global climate? Use information from our lab to support your response.

Appendix D3

Back of the Envelope calculation to convince myself that the ice-albedo feedback dwarfs the latent heat capacity of ice.

The North Pole is in sunlight for six months every year. Treating the North Pole as a typical point on the Arctic Ocean makes the calculations much simpler than doing the calculus required for a rigorous calculation. I have the vague sense that this is a conservative estimate– that places at lower latitude on average receive more sunlight than the North Pole, even during the northern summer. But I am not positive of this.

During the summer the sun moves from the horizon (90° from zenith) to 67° from zenith and back to the horizon. This movement is complex, but for the purposes of the back of the envelope calculation, I will use a rough average of 78°.

The solar irradiance at the earth's surface with the sun at zenith is 1050 W/m^2, so:

$$\text{Average summer-time irradiance at North Pole} = 1050 * \cos(78°) = 218\ W/m^2$$

The albedo of sea ice is assumed to be 0.6, and the albedo of water at an incident angle 78° is assumed to be 0.25.[40] This makes a difference of 0.35, and so if all the ice were to melt, the:

$$\text{Change in solar flux due to change in Albedo} = 0.35 * 218 = 76\ W/m^2.$$

The average summer time surface area of sea ice is assumed to be $1 \times 10^7\ km^2$,[41] which is $1 \times 10^{13}\ m^2$:

$$\text{Total change in power over Arctic Sea Ice} = 76\ W/m^2 * 1 \times 10^{13}\ m^2 = 7.6 \times 10^{14}\ W$$

Assuming a mean summer-time sea ice volume of 20,000 km^3, and assuming that ice has a density of 0.917 Kg/L.[42]

$$2 \times 10^4\ km^3 = 2 \times 10^{16}\ L$$

$$(2 \times 10^{16}\ L) * (0.917\ kg/L) = 1.83 \times 10^{16}\ \text{kg of ice.}$$

[40] http://en.wikipedia.org/wiki/Albedo
[41] http://www.ijis.iarc.uaf.edu/en/home/seaice_extent.htm
[42] http://psc.apl.washington.edu/wordpress/wp-content/uploads/schweiger/ice_volume/BPIOMASIceVolumeAnomalyCurrentV2.1_CY.png

The latent heat of fusion for water is 334 KJ/Kg so the latent heat of fusion in summer sea ice is:

$$\text{Energy needed to melt all the sea ice} = 1.83 \times 10^{16}\ \text{kg} * 334\text{KJ/Kg} = 6.13 \times 10^{18}\ \text{KJ}$$

$$= 6.13 \times 10^{21}\ \text{J}$$

Time need to melt all the sea ice if all of the excess power were used to melt ice:

$$= (6.13 \times 10^{21}\ \text{J}) \div (7.6 \times 10^{14}\ \text{W}) \approx 8 \times 10^{6}\ \text{seconds}$$

(Around 90 days)

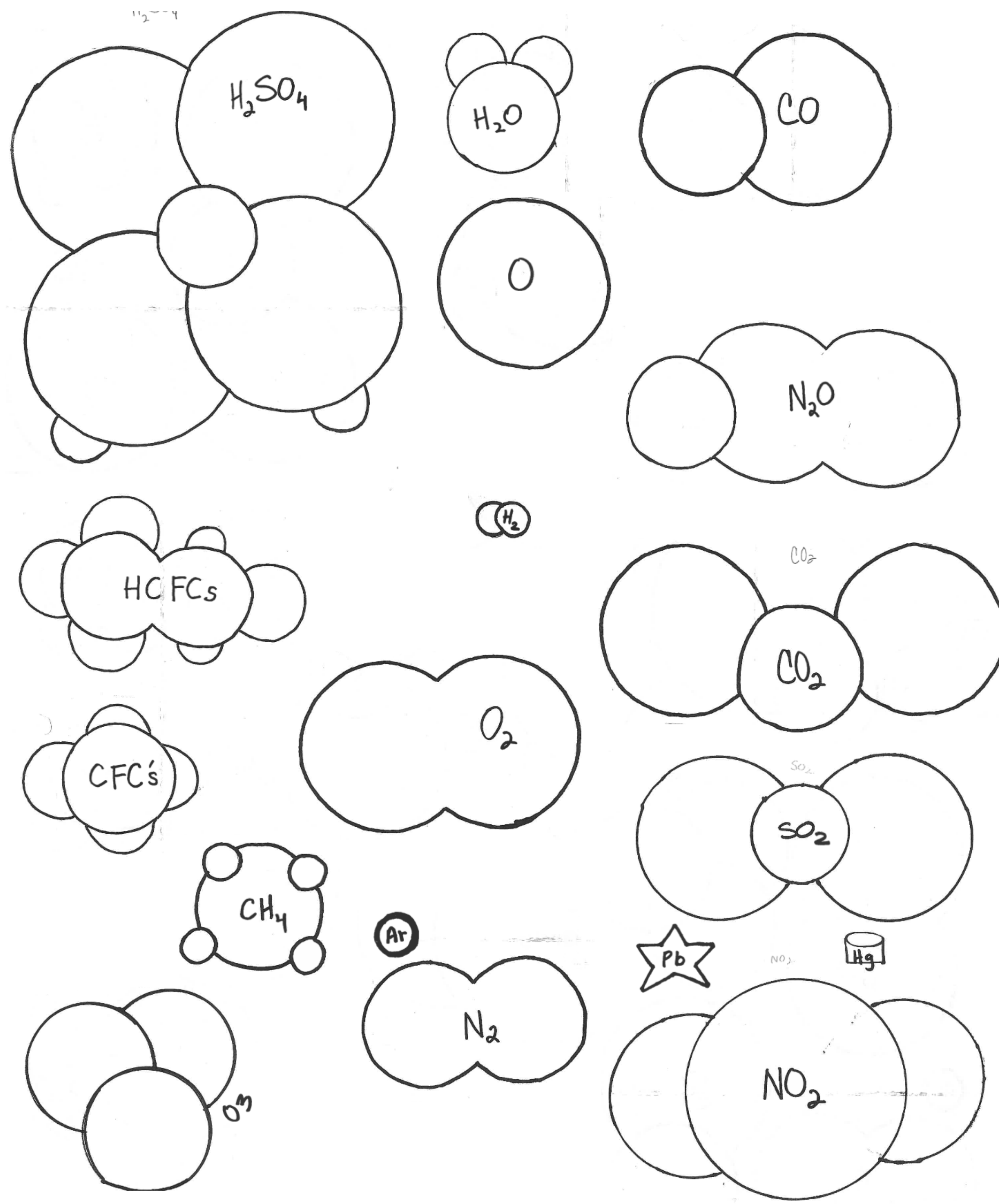
Therefore in a single summer, if the all the arctic sea ice were to melt, the ice-albedo feedback would add about enough energy to the Earth's energy stock to melt the arctic sea ice twice. When considering climate change, it is typical to think in terms of decades, centuries or millennia, not months.

APPENDIX E

MATERIALS ASSOCIATED WITH ANNETTE BROWN

APPENDIX E1

Air Molecule Cards use in Annette Brown's class to review constituents of the air and major air pollutants. (Note: Cards were much bigger, the CO_2 card is 8" across.)



APPENDIX E2

Handout Annette Brown's students completed while reading through the online materials

at http://www.earthobservatory.nasa.gov/Features/CarbonCycle/page1.php

Name ____________________________ **Date** ____________________ **Period** ____________

Lab 4: The Carbon Cycle –Day 1 Part 2

Question Sheet

Q1: Identify two sources of carbon in the picture. Identify two sinks.

Q2: Where did the 9 petagrams of carbon emitted into the atmosphere by anthropogenic activities in 2010 end up going?

Q3: If that wheatgrass were out in nature (instead of in a videographer's studio), what would happen to the carbon captured in the wheatgrass once it died?

Q4: Green plants both photosynthesize (causing them to act as a carbon sink) and respire (causing them to act as a carbon source); based on the carbon cycle picture to the right above, are these plants a net sink or source of carbon?

Q5: People have concerns about the use of slash and burn (http://geography.about.com/od/urbaneconomicgeography/a/slashburn.htm), partly because it affects the carbon cycle in two different ways. What are those two ways?

Q6: Overall, is there a greater amount of carbon exchanged between the atmosphere and the biosphere, or between the atmosphere and the hydrosphere?

Q7: How did the amount of carbon absorbed by the hydrosphere compare to the amount carbon released by the hydrosphere in 2010?

Q8: Which form of fossil fuel did you expect would have contributed the most to carbon dioxide production? Which form actually contributes the most?

Q9: In the Plant Bowen picture, the cooling towers are highlighted. Many people incorrectly link the presence of cooling towers to the presence of nuclear power plants, but all large-scale power plants have them. In the Plant Bowen picture, the cooling towers are highlighted. Many people incorrectly link the presence of cooling towers to the presence of nuclear power plants, but all large-scale power plants have them. What is it that is coming out of the cooling towers? (Hint: This has an important relationship to the matter cycle you considered in the Troposphere lab.)

Q10: What is meant by 'fracking'?

Q11: What are the benefits –and the risks –with getting natural gas and oil from shale through the fracking process?

Q12: What do you think would be the effect on life on this planet if the kind of net release of carbon described above for 2010 were to continue for the next 20 years?

Lab 3 Day 1 Part 3

Q13: What has been the general trend in the sizes of sources and sinks from 1959-2010?

Q14: For each year, what is the relationship between the magnitude of carbon emissions and the magnitude of carbon uptake?

Q15: How does the trend in fossil-fuel emissions differ from the trend in land-use change emissions?

Q16: For the source that had the largest increase over those years, what do you think was responsible for that increase?

Q17: From what regions/countries was most of the carbon emitted in 1950?

Q18: From what regions/countries was most of the carbon emitted in 2010?

Q19: What has been the general trend in the amount of carbon taken up by the atmosphere, oceans, and terrestrial biosphere over the last 50+ years?

Q20: How did carbon uptake during 2001-2010 differ from carbon uptake during 1959-1968? Where has more and more of the carbon been going?

Q21: What was that anomaly? Provide some reasonable hypothesis for what might have caused the unusual data collected in that year?

Q22: Why was the uptake of carbon in 1992 so much larger for the terrestrial biosphere than for the atmosphere and oceans (i.e. why did that anomaly in the 1992 data occur)? Does this match the prediction in Q21?

Lab 3 Day 1 Part 4

Q23: How can carbon be transferred between the atmosphere and Earth's other spheres?

a. photosynthesis transfers carbon <u>from</u> the biosphere

b. respiration transfers carbon <u>to</u> the biosphere

c. the burning of fossil fuels and vegetation transfers carbon <u>to</u> the atmosphere

d. the dissolution of methane in seawater transfers carbon <u>to</u> the hydrosphere

Q24: How would you describe changes in fossil-fuel carbon emissions from 1959 to 2010?

a. emissions decreased, with the United States having the largest decrease

b. emissions decreased, with China having the largest decrease

c. emissions increased, with the United States having the largest increase

d. emissions increased, with China having the largest increase

Q25: How would you best describe general changes in the uptake of carbon by the atmosphere, oceans, and terrestrial biosphere from 1959 to 2010?

a. the atmosphere, oceans, and terrestrial biosphere became smaller carbon sinks

b. only the oceans and terrestrial biosphere became smaller carbon sinks

c. the atmosphere, oceans, and terrestrial biosphere became larger carbon sinks

d. only the oceans and terrestrial biosphere became larger carbon sinks

APPENDIX E3

Impromptu lesson on the chemistry of greenhouse gases. This discussion mainly took place in front of Annette's white board, and I was drawing pictures as we talked.

Len: I don't know if you have the time. But you know that the light that comes into the Earth is primarily UV and visible.

AB: Is the spectrum UV and visible?

Len: Yeah. So from high to low, and we'll just talk about what surrounds what we can see. So you've got UV, then it's ROYGBIV backwards, then infrared. So infrared is lower frequency than visible.

AB: Yeah, that was on that lab they gave us.

Len: Yeah, and you can go either way, like red on the left, and violet on the right.

AB: Yeah… Wait is that frequency?

Len: Yeah, so I'm going from high frequency to low frequency.

AB: OK.

Len: And the reason I'm doing it this way is: When they draw what they call black body curves, they almost always draw it that way, with high to the left and low to the right. At some level it's arbitrary, but when they look at black body curves, they always put high to the left. So both the sun and the earth can be considered at a simple level to be black bodies. And that means that they glow when they're hot. So the sun glows at all different frequencies, but the peak is, say here-ish, between the visible and ultraviolet. So that's why we can see the sun glowing, because it's emitting a lot of visible light. The earth is much colder than the sun, so the Earth glows almost not at all in the visible, and but then it glows a lot in the infrared. Basically at any moment in time–I know right now the Earth is warming–but at any moment in time, we're essentially in balance, so the amount of radiation that's coming in from the sun equals the amount that's going out into space.

AB: Basically energy.

Len: Yeah, so the energy coming in is equal to the energy going out. Now some of the sunlight just gets reflected back out into space, so that's the albedo. It's really the energy that's absorbed in these hot frequencies that's equal to the energy emitted in these cooler frequencies. And at any moment in time, these two should be more or less in balance. Now in reality, they're never perfectly in balance, so the Earth is either going to be warming up or cooling off. So if we're warming up, we're not emitting quite as much energy as we're absorbing. What ends up happening is that the troposphere, the part of the atmosphere that we live in, is basically transparent to this stuff (The UV). So the light from the sun can more or less come in through the atmosphere, at least the part where we live. Some gets reflected by clouds, so it's not 100% transparent, but we count clouds with albedo. But we're definitely not 100% transparent to this stuff [the infrared]. And what makes us non-transparent is greenhouse gases. So the greenhouse gases absorb in these frequencies. And in order to emit as much as we need to balance out, we actually have to warm up a little bit, so we can glow a little more. So we're not a perfect black body because of the carbon dioxide. So if it weren't for greenhouse gases, and we were a perfect emitter of this stuff, the planet would actually be freezing.

AB: It would be what, negative 15 degrees?

Len: I forget the exact number. But significantly colder, like it would be a snowball earth. But because we're not a perfect emitter, some of this gets re-radiated, and we end up being warmer. That was a bad explanation, but the bottom line is that the CO_2 and the CH_4 absorbs this stuff, and in order to absorb it, the molecule needs to be able to absorb the energy. And the way they absorb this infrared is not like an electron absorbing a photon and going to a higher energy level, like typical high school chemistry stuff. But actually, the molecule can vibrate in different ways.

AB: So because of its structure.

Len: Yes. So when it absorbs, the water, I can't say specifically, but they talk about the carbon dioxide, and analogous things will happen. So there's a freedom of motion where the carbon can oscillate between the two oxygens. So the carbon can move back and forth, a little closer to this oxygen, and then a little closer to the other one. And that oscillation means it can absorb energy and start oscillating. And that energy absorption happens in the infrared.

AB: So it's all about structure.

Len: Yeah. And you couldn't have that kind of absorption with oxygen or nitrogen, because the two atoms are the same. The oxygen in water might move between the two hydrogens, but there are also the unbonded electrons on the other side, so I don't know which is more important. CH_4 has four hydrogens, not just two oxygens, so that probably makes it more complex than CO_2.

AB: And methane is 21 times stronger. [as a greenhouse gas]

Len: And that probably has something to do with its structure. But I don't know the details. But all the greenhouse gases are like two different things, and there's a freedom of motion, between how these different nuclei can move that doesn't exist when the two nuclei are identical.

AB: Hmm.

Len: So that's what I was trying to tell that kid. I didn't want to tell him which molecules were greenhouse gases, but I wanted him to look for molecules that weren't just one atom or two identical atoms.

APPENDIX F

MATERIALS ASSOCIATED WITH TOM BUTLER

Appendix F1

Handout used in Tom Butler's class while discussing *The Day After Tomorrow*

Transcript from the movie *The Day After Tomorrow*

A. Key words:

Cataclysmic means disastrous, or very, very bad.

Paradox means a statement or situation that seems crazy or impossible, but in fact is or may be true.

Temperate means mild. Temperate climate means a climate that is not too hot and not too cold.

Fragile means easy to break or damage or harm.

B. Scene: U.N. Conference on Global Warming, New Delhi, India

Dr. Jack Hall: What we have found locked in these ice cores is evidence of a ***cataclysmic*** climate shift that occurred around 10,000 years ago. The concentration of these natural greenhouse gases in the ice cores indicate that runaway warming pushed this planet into an ice age that lasted for two centuries.

Country Representative: I'm confused. I thought you were talking about global warming, not an ice age.

Dr. Hall: Yes, it is ***a paradox***. But global warming can trigger a cooling trend. Let me explain. The Northern Hemisphere owes its **temperate** climate to the North Atlantic Current. Heat from the sun arrives at the equator and is carried north by the ocean. But global warming is melting the ice caps and disrupting this flow. Eventually it will shut down and when that occurs, well, there goes our warm climate.

Vice President of the United States: And who is going to pay the cost of the Kyoto Accords? It would cost the world's economies hundreds of billions of dollars.

Dr. Hall: With all due respect, Mr. Vice President, the cost of not doing anything could be even higher. The climate is ***fragile***. At the rate that we are burning fossil fuels and polluting the environment, the ice caps will soon disappear.

Vice President of the United States: Professor Hall, our economy is every bit as fragile. Maybe you should keep that in mind before you start making sensationalist claims.

Dr. Hall: Well, the last chunk of ice that fell off was about the size of the state of Rhode Island. I think some people might call that pretty sensational.

APPENDIX F2

Website Tom Butler Provided to Support Students' Research

The website Tom Butler developed for his class to use had a very simple layout. Each page had a header with its own image and several common tabs. In addition to the home page (See Figure 38), there were eight other pages each of which contained a number of text-links.

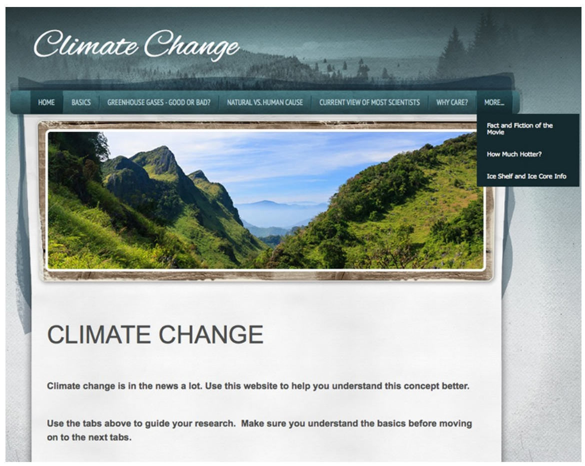


FIGURE 38
Mr. Butler's website on climate change. Homepage with cursor over "More" tab.

TABLE F2

Links and associated text for each of the pages on Tom Butler's website.

Linking Text	Link
BASICS	
BrainPop Global Warming	http://www.brainpop.com/science/ourfragileenvironment/globalwarming/
BrainPop Greenhouse Effect	http://www.brainpop.com/science/earthsystem/greenhouseeffect/
What is the difference between climate and weather?	http://www.epa.gov/climatestudents/basics/concepts.html
What is climate change?	http://www.epa.gov/climatestudents/faq.html
Is "Climate Change" the same as global warming?	http://www.epa.gov/climatestudents/faq.html
What are greenhouse gases?	http://www.epa.gov/climatestudents/basics/today/greenhouse-gases.html

What is the greenhouse effect?	http://www.epa.gov/climatestudents/basics/today/greenhouse-effect.html
Greenhouse Effect Video (On student computers.)	http://www.epa.gov/climatestudents/basics/today/greenhouse-effect.html
Climate Change Video (On student computers.)	http://www.epa.gov/climatechange/kids/
GREENHOUSE GASES–GOOD OR BAD	
The National Center for Atmospheric Research–Kid-friendly website. Make sure to read the 3rd paragraph very carefully!	http://www.eo.ucar.edu/kids/green/warming4.htm
NATURAL VS. HUMAN CAUSE	
What are some things in nature that can cause earth's temperature to rise? For bonus points, try to figure out why scientists think these natural things are not the cause of our current temperature increase.	http://www.epa.gov/climate/climatechange/kids/basics/past.html
What are some human activities that can cause earth's temperature to rise?	http://www.epa.gov/climate/climatechange/kids/basics/past.html
Look at the graph above. What do you think it says about today's cause of earth's warming temperature? Click here to learn more about the graph and what it means.	http://www.epa.gov/climatechange/science/overview.html
CURRENT VIEW OF MOST SCIENTISTS	
According to the Intergovernmental Panel on Climate Change (the "IPCC"), "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century". Click here to learn more.	http://www.realclimate.org/index.php/archives/2013/09/the-new-ipcc-climate-report/
What is the IPCC?	http://www.windows2universe.org/earth/climate/ipcc_in_depth.html
WHY CARE?	
So, What is the Big Deal? Click here to learn more.	www.kidsnewsroom.org/climatechange/bigdeal.html
Impacts of Climate Change	http://www.epa.gov/climate/climatechange/kids/impacts/index.html
FACT AND FICTION OF THE MOVIE	
National Geographic News	http://news.nationalgeographic.com/news/2004/05/0527_040527_DayAfter.html
Center for Climate and Energy Solutions	http://www.c2es.org/science-impacts/climate-science-realities-misconceptions/day-after-tomorrow#8
Is the Larsen B ice shelf real? Did it collapse?	http://earthobservatory.nasa.gov/Features/WorldOfChange/larsenb.php
More Larsen B ice shelf information	http://news.bbc.co.uk/2/hi/sci/tech/1880566.stm
HOW MUCH HOTTER?	
How much do scientists predict temperatures will rise in the next 100 years? Click here to find out these answers.	www.kidsnewsroom.org/climatechange/bigdeal.html

ICE SHELF INFORMATION	
What is an ice shelf?	http://www.kidsdiscover.com/did-you-know/on-the-ice-shelf/
What is the difference between an ice shelf, an ice sheet, and a glacier?	http://icestories.exploratorium.edu/dispatches/big-ideas/ice/
Is the Larsen B ice shelf real? Did it really crack?	http://earthobservatory.nasa.gov/Features/WorldOfChange/larsenb.php
More Larsen B information	http://news.bbc.co.uk/2/hi/sci/tech/1880566.stm
Is There a Larsen A ice shelf?	http://earthobservatory.nasa.gov/Features/LarsenIceShelf/
What can ice cores tell us? See Mr. Butler's journal from Greenland.	Link withheld to protect participant's confidentiality.
More ice core information from the American Museum of Natural History.	http://www.amnh.org/exhibitions/past-exhibitions/climate-change/changing-atmosphere/whats-an-ice-core

APPENDIX F3

Handout Tom Butler's students used in "Elevator into Space" activity.

How Much Carbon Dioxide is in the Air?

Go to FOSSWEB at http://archive.fossweb.com/modulesMS/ and click on "Weather & Water". Next click on "Weather & Water Multimedia". Type "[deleted]" in the username box, "[deleted]" in the password box, and "your status" as student then click "login." Last, click "Enter the Program". Followed by "continue." When the CONTROL ROOM screen comes up, click on "Atmospheric Data" and choose "Elevator to Space" from the dropdown menu. Work through the simulation by collecting data from each level and record readings below.

Distance from Ground	Layer	Density	Amount of O_2	Amount of N_2	Amount of other gases
0 km	*Troposphere*	*1.2 kg/m³*	____%	____%	____%

Conclusions:

What happens to the density (thickness) of the air as you go higher up?

How much carbon dioxide is in our air?

Appendix F4

Questions for the 'Stuck Jar' in Tom Butler's class.

These were cut into individual questions, and if a group ran out of things to talk about, they could reach into the jar, and discuss that question.

At the beginning of the movie the scientists were working on a large shelf of ice. Where were they? Is this a real place and did something really happen there or is it just a special effect for the movie?

Dr. Hall says, in his talk at the UN: "the concentration of these natural greenhouse gases in the ice cores, indicate that runaway warming pushed the planet into an ice age that lasted 2 centuries". What are greenhouse gases and what do they do?

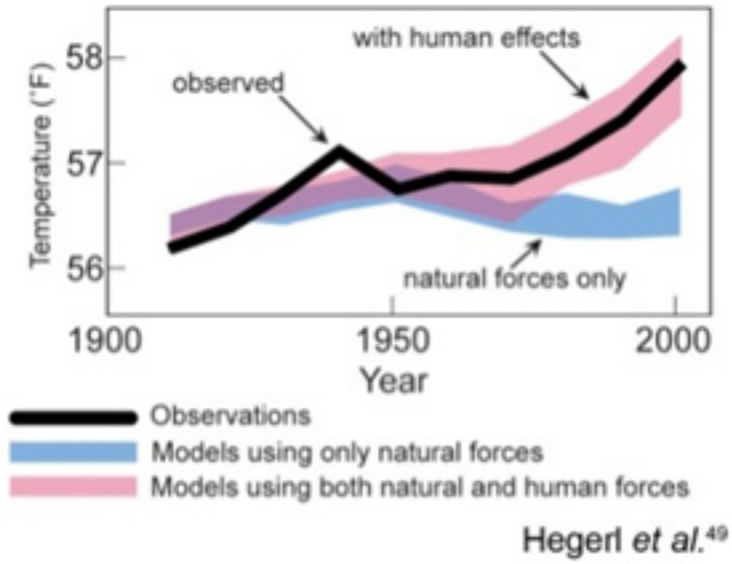
Is global warming real? Is it a natural process or something that humans have caused? Is it a big deal if the earth gets few degrees warmer? Why or why not?

Dr Hall claims that global warming is going to cause major climate change. What do you think global warming is? What do you think are some of the causes of global warming?

Dr. Hall, while talking to the UN, says that if we don't stop burning fossil fuels, then global warming will continue and the climate will change dramatically. What are fossil fuels and what do they have to do with global warming?

Dr. Hall jumped across the cracking ice shelf to get ice core samples? What are ice cores and how do they help scientists learn about what our air was like in the past?

Look at this graph from the U.S. Environmental Protection Agency's website. What is the x-axis labeled? What is the y-axis labeled? What does this data mean to you?



How much has earth's average temperature risen in the last 100 years? What is the prediction for the increase in earth's temperature for the next 100 years?

In the movie, global warming caused the next ice age. Do scientists think that this is likely to happen?

Is climate change a big deal? Explain your answer.

APPENDIX F5

Assignment sheet for geoengineering project.

Name: __________________ Period:___ Partner:___________

Climate Change Poster Project (due on __________)

I. Background Information

Humans are creative. They try to solve problems in original ways. Because many humans are concerned about the planet getting warmer because of the amount of greenhouse gases in the air, some scientists have come up with very clever ways to deal with this issue. Like most ideas, there are pros (good things) and cons (bad things). Their ideas can be grouped into two categories:

A. Ways to limit the amount of sun that reaches Earth (so the Earth won't get so warm)

1. **Space Mirrors** (Put a Giant Mirror or Mirrors into Space to Make Some of Sunlight Bounce Back to Space).
2. **Artificial Volcanoes** – pump sulfur into the air, just like a volcano, so sunlight can hit the sulfur and bounce back into space.
3. **Cloud-Making Ships**
4. **White Roofs**
5. **Painting Mountains White**

B. Ways to remove large amounts of greenhouse gases from the air.

1. **Artificial Trees (or other Air Scrubbers)**
2. **Seaweed Farms**
3. **Dumping Iron into the Ocean**
4. **Greening the Desert**
5. **Storing Carbon Dioxide Underground or in the Ocean**

Your poster should:

1. In two sentences or less, define "climate change" and explain what type of gases can cause climate change.

   ____

   ____.

2. Describe the solution you researched. Add important details from your research.

____

____

____.

3. Explain how the solution will keep the Earth from getting too warm.

____

____.

4. Explain the pros (good things) and the cons (bad things) of the solution. Make sure to list at least two of each.

Pros (Good Things)	**Cons (Bad Things)**
1.	1.
2.	2.

5. Have a drawing of the "greenhouse effect" as it works now, and a second drawing of the greenhouse effect as it would work if scientists try your solution.

Remember, you have great ideas so make sure you use your own words. A good rule of thumb is that if you don't know what a word means, you shouldn't use it in your product because other people won't know it either.

Be creative! Be neat! Proofread your work!

APPENDIX F6

Readings (and one video) provided to students to aid their research on geoengineering.

Source	Link
SPACE MIRRORS	
Popular Science	http://www.popsci.com/environment/article/2005-06/how-earth-scale-engineering-can-save-planet
Science Daily	http://www.sciencedaily.com/releases/2010/09/100920123916.htm
ARTIFICIAL VOLCANOES	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
The Telegraph	http://www.telegraph.co.uk/science/science-news/8761883/Scientists-to-create-artificial-volcano-for-climate-change-experiment.html
CLOUD MAKING SHIPS	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
WHITE ROOFS	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
PAINTING MOUNTAINS WHITE	
CNN (Video)	http://edition.cnn.com/2011/11/28/world/americas/peru-mountain-whitening/index.html
Green Living Ideas	http://greenlivingideas.com/2010/06/22/geoengineering-peru-paints-mountain-white-save-glacier/
ARTIFICIAL TREES	
MSNBC	http://www.nbcnews.com/id/30251856/#.UzieZ17TZ3c
PhysicsWorld.com	http://physicsworld.com/cws/article/news/2009/aug/27/engineers-call-for-artificial-trees-to-reduce-carbon-dioxide
SEAWEED FARMS	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
DUMPING IRON INTO THE OCEAN	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
GREENING THE DESERT	
National Geographic	http://news.nationalgeographic.com/news/2010/03/photogalleries/100324-global-warming-geoengineering-pictures-asilomar/
STORING CARBON DIOXIDE UNDERGROUND	
Innovations-Report.com	http://www.innovations-report.com//html/reports/environment-sciences/report-30686.html