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An examination of climate scientists' participation in education:  
Implications for supporting the teaching and learning of socially controversial science

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A dissertation  
submitted in partial fulfillment of the  
requirements for the degree of

Doctor of Philosophy

University of Washington  
2012

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Program Authorized to Offer Degree:  
College of Education

University of Washington

**Abstract**

An examination of climate scientists' participation in education:  
Implications for supporting the teaching and learning of socially controversial science

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Preparing a generation of citizens to respond to the impacts of climate change will require collaborative interactions between natural scientists, learning scientists, educators and learners. Promoting effective involvement of scientists in climate change education is especially important as climate change science and climate impacts are scientifically complex and are entangled in a persistent social controversy. Using ethnographic methods, including observations of meetings, classrooms, professional development workshops, interviews and surveys of teachers, scientists and students, this dissertation provides a window into two climate science educational efforts in which climate scientists played integral roles in either curriculum development or classroom enactment. It explores scientists' participation and student learning through four stand-alone but related articles that focus on the following questions:

1. What are the implications of the social controversy for the teaching and learning of climate change science? How do the political dimensions of this controversy affect learners' attitudes towards and reasoning about climate change and climate science?

2. What is the role for climate scientists in climate change education? What scientific and pedagogical expertise do scientists bring to their educational work and what are challenges and strategies for scientists' inclusion in K-12 education?

The first paper describes the current social context for the teaching and learning of climate change science, and outlines conceptual, epistemological and decision-making goals for climate change education. The second paper explores how high school students' reasoning about climate change science occurs at the intersection of political and scientific ways of knowing, doing and being, and examines the implications of this for scientist involvement in climate change education and professional development for teachers. The third describes how climate scientists leveraged their existing scientific practices and inquiry approach to solve problems through participation in a scientist-led climate science curriculum development project. The final paper identifies challenges the scientists faced in their involvement in both curriculum development projects and suggest strategies to promote effective scientist-educator and scientist-student interactions.

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## ACKNOWLEDGEMENTS

Every scholarly work rests on the shoulders of countless individuals who support the transformation of an idea into a study into an argument on a page. Hundreds of people contributed in some way to this work, intellectually, emotionally and financially. While I am unable to acknowledge all of them individually here, I would like to express the gratitude I feel to all of those who helped with the creation of this document and the scholarly journey that creation entailed.

First of all, I would like to thank my advisor and the chair of my committee, Philip Bell, for his guidance, optimism, and insight that have deeply shaped this work and myself as a learning scientist. I feel incredibly fortunate to have had the opportunity to work with him for the past three years. I am deeply grateful to Richard Keil, my co-advisor for my masters in oceanography, who stayed with me during my graduate career, bringing his scientific expertise as a member of my doctoral committee. Leslie Herrenkohl and Mark Windschitl served as members of my committee, and I am indebted to them for their invaluable critiques and suggestions that helped me see ideas in new ways, and more deeply explore the intellectual landscape.

Many members of the Everyday Science and Technology Group and the research team for the life sciences and English Language Arts course development project have been instrumental in this work through research support, collaboration on curriculum and, most importantly, a vibrant and ongoing discussion of ideas. I would like to especially acknowledge the contributions of Chloe Diamond, Ann Ferguson, Nancy Price, Blakely Tsurusaki and Carrie Tzou.

I was lucky enough to be part of not one but two amazing and inspiring academic cohorts—the oceanography class of 2004, and the learning sciences incoming class of 2009. I feel truly honored to have been a part of both of these groups, and am looking forward to the collaborations and years of academic work still to come!

I would like to extend my deepest thanks to the scientists, teachers and students who participated in these studies for generously allowing me into their lives. Their insight and enthusiasm inspired me as I worked on this project.

Finally, I would like to acknowledge the support of my family, without whom this dissertation would not have materialized. Especially, thank you to my parents, Matthew and Mary Walsh, for reading drafts, dealing with panicked phone calls, and your unwavering support and encouragement.

## DEDICATION

*To my family, who was on my side,  
and  
To Toby, who was by my side.*

## Introduction to the Dissertation

Scientists estimate that the average global temperature has increased by 1.5°C since 1880. Arctic sea ice is disappearing at a rate of 12% by area per decade, sea level is increasing at a rate of 3.19mm per year, and atmospheric carbon dioxide (CO<sub>2</sub>) is well on its way to doubling the pre-industrial value, increasing from ~280 ppm in 1850 to 393 ppm in 2012 (IPCC, 2007a, “Global climate change: Vital signs of the planet”, 2012). These changes are expected to have significant consequences for resource availability across the globe (IPCC, 2007a). Preparing a generation of citizens who can use scientific evidence to respond effectively to anticipated impacts of climate change is perhaps the greatest educational challenge that we will face in the coming century. It will require the concerted efforts of scientists, educators and learners, collaborating effectively to address the obstacles we face. The need for increased attention to learning of climate-related science is reflected by the attention to climate change science in the vision for K-12 education outlined in the New Framework for K-12 Science Education (NRC, 2011) and in the significant presence of these topics in the preliminary draft of Next Generation Science Standards (NGSS, 2012).

I became interested in climate change education as a scientist researching topics related to past climate changes as a graduate student in oceanography. I’ve always had an interest in teaching, and in oceanography I participated in teaching and outreach activities in oceanography, climate science and climate change<sup>1</sup>. In 2006, two years into my graduate

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<sup>1</sup> In this dissertation, I make a distinction between *climate science*, *climate change*, and *climate change science*. *Climate science* deals with investigations into the mechanisms that control the climate system, including an equilibrium and baseline understanding of how climate works prior to human perturbations. *Climate change science* generally refers to

career, Al Gore's movie, *An Inconvenient Truth* was released, and shortly thereafter in 2007 the Intergovernmental Panel of Climate Change (IPCC) released their fourth assessment report on climate change. Climate change gained momentum in public spheres, and those of us in the climate science community were increasingly called on to speak to and answer questions about climate change. Over time, I became cognizant of and intrigued by the social controversy surrounding climate change and the ways that it colored the perceptions and attitudes of the people with whom I interacted. Given that the scientific community had generally reached a consensus about the causes of climate change in 2001, why was this still so controversial outside of the scientific community? Naively, I wondered how much information people would need before the social controversy resolved. But climate change education is not merely a matter of *information*, as I learned. It is more complex than that, and understanding and addressing these complexities is one aim of this dissertation.

Climate change education research is in its infancy. While the educational community (generally) agrees that supporting a generation of citizens who are motivated and equipped to respond to climate change impacts is a valid goal of science education, as a community of researchers we are just beginning to document and understand how to support student engagement with and learning about climate change, given its scientific and social complexity. Climate change education will necessarily require the involvement

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studies of recent perturbations to the normal workings of the climate system (though one can also talk about past climate changes). *Climate change*, as will be discussed in this dissertation, has become infused with political and social overtones, and can evoke the broader social context, and implications for humans that go beyond the scientific endeavor. Thus, an effort will be made to refer only to "climate science" or "climate change science" when describing the scientific endeavors, and "climate change" when speaking more broadly.

of natural scientists who, at the very least, are in a position to facilitate access to the current scientific data and ideas. As a natural scientist turned educational researcher, I was surprised to discover that the literature on scientist involvement in science education was relatively thin, despite the strong theoretical basis for including disciplinary experts in education. This dissertation contributes to this literature by exploring how scientists are currently participating in climate change education, and how the educational community can support their participation.

In this work, I approach the issue of climate change education from multiple angles. I consider the challenges involved for students, scientists and educators in climate change teaching and learning. I describe educational resources and learning experiences intended to promote scientific understandings of climate change. I explore the underlying political, scientific and pedagogical dimensions at play as learners engage in climate change science and scientists engage with climate change education. The four chapters of this dissertation address the following research questions:

1. What is the socio-political context for climate change education, and how does that inform the goals of climate change education?
2. How do political and scientific ways of knowing, doing and being influence high school students' attitudes toward and understandings of climate change science and how can we promote student engagement in and learning of climate change science?
3. How do scientists participating in climate change education leverage new and existing scientific and learning principles associated with knowing, being and doing?

4. What are challenges, strategies, and opportunities associated with educators and scientists coming together to engage productively in climate science education efforts? How can we productively arrange and optimize scientist-educator partnerships?

### *Format of Dissertation*

This dissertation is composed of four chapters, each written as a stand-alone paper that addresses a particular dimension of climate change education and scientist involvement in climate change education. Because this is constructed as a series of articles, there is some redundancy in the content, both in the description of the conceptual frameworks, the background information and study and analysis methods. Some ideas that are mentioned briefly in a particular paper are more extensively described in others, or are presented from a different perspective. In many of these cases, I have indicated these redundancies using footnotes.

### *Study Design*

This dissertation focuses on two climate science and climate change curriculum development and enactment projects. The two projects are similar in that they share the goal of connecting high school students with exciting authentic scientific practices and cutting-edge content knowledge. They differ in the roles that the scientists play in the development of the curriculum, the level of involvement of the scientists with teachers and educators, and the relationships among the scientists.

The first setting is two six- to seven-week long pilot enactments of an *Ecological Impacts of Climate Change* unit in high school classrooms. In this unit, students learn about causes of climate change and construct arguments for how climate changes may affect species in local or global ecosystems. An interdisciplinary team including climate scientists, ecologists and learning scientists partnered with teachers to develop this curriculum. In enactments, the scientists supported students by answering student questions and providing iterative feedback on student work via a social networking platform and visiting the classroom to facilitate activities and view student presentations. The second setting, the development of a *Dual-Credit Climate Course* is a scientist-led effort to transform an undergraduate sophomore-level climate science and climate change course into a course appropriate for upper-level high school students. In this project, scientists partnered with high school teachers to create curricular materials and held professional development workshops on climate science and climate change for the high school teachers.

To engage with my four guiding research questions, I use multiple data sources from these study contexts, including observations of classroom enactments, meetings and professional development workshops; interviews with teachers, students and scientists; exit surveys with scientists in the second pilot enactment; curricular artifacts including scientist-created curricular materials, student work and scientist feedback on student work; qualitative field notes; teacher and scientist daily exit surveys from professional development workshops and weekly student engagement surveys from pilot enactments. These data are used to elucidate scientist, student and teacher experiences with

constructing and participating in learning experiences related to climate science and climate change.

### *Synopsis*

This dissertation begins with an examination of the roots of the social controversy around climate change, and the implications of this controversy for climate change education. Because of the deep societal implications of climate change, climate education should be a priority for science educators. However, the social context and scientific complexity of climate change education provide challenges to learners' engagement with and participation in climate science. Climate change is currently poised on the edge of a public educational controversy similar to that faced by the teaching of evolution. In the first chapter of this dissertation, I assess the current context for the teaching and learning of climate science and propose learning goals across three dimensions of the science: (a) epistemological understandings and knowledge of the scientific enterprise, (b) conceptual understanding of the climate system and current change, and (c) effective decision-making and participation in climate change impacts adaption and mitigation.

Chapter 2 explores the influences of the politically-charged social controversy and the scientific complexity of the subject matter on student attitudes towards and conceptual understandings of climate change science. I present five qualitative case studies of high school students' pathways through the second pilot of the Ecological Impacts of Climate Change unit. These students had a range of initial views of climate change, including two students who initially rejected the scientific consensus of human-influenced climate change. Using Herrenkohl and Mertl's (2010) framework of *knowing, being* and *doing*, I

describe the interactions of the political and scientific ways of knowing, being and doing the students leveraged as they reasoned about scientific evidence for climate change. These case studies indicate that supporting student learning of climate science requires space to voice and explore ideas and beliefs that may be in tension with the science, access to deep disciplinary expertise and data, and the opportunity to revisit ideas multiple times. This is likely particularly crucial for students who initially challenge the scientific consensus.

Chapter 3 explores the educational work of practicing scientists, who play an integral role in teaching and learning about socially relevant contemporary sciences like climate change. I examine the participation of climate scientists in a high school climate science curriculum development effort and describe how scientists draw on aspects of their scientific process as well as past experiences as teachers and students in their design of curriculum. The extent to which the participants' scientific ways of knowing, being and doing informed their participation in the curriculum development project is a marked example of how individuals' prior ways of knowing, being and doing shape their participation in new contexts.

Finally, in Chapter 4, I draw from both study contexts to explore challenges that the scientists encountered when supporting teachers' and students' participation in the practices of climate science. I consider scientists as participants in scientific subcultures and examine the tensions that arose for these scientists when crossing boundaries into educational contexts. When promoting teacher and student participation in scientific processes, scientists struggled to anticipate challenges for learners, not only with respect to their conceptual understandings, but also the epistemic, social and technological dimensions of the scientific practice. I explore implications for supporting the teaching and

learning of scientific practices in scientist-educator and scientist-student interactions, and I suggest strategies to help scientists, educators and students interact more productively with each other.

## Chapter 1

### Epistemological, Conceptual and Decision-Making Dimensions of Climate Change Education in 21<sup>st</sup> Century America

#### Introduction

Sixty years ago scientists implicated human emissions of CO<sub>2</sub> as a mechanism of possible societally consequential climate changes (IPCC, 2007a). Despite the potential severity of climate change, half a century passed from the initial reports of the projected negative consequences of this human-influenced, or *anthropogenic*, climate change before public engagement with climate science and climate change education gained momentum.<sup>2</sup> Currently, many Americans do not believe that global warming is a real phenomenon, that climate change is anthropogenic, or that climate change will affect their everyday lives (Kohut, Doherty, Dimock & Keeter, 2010; Leiserowitz, Maibach, Roser-Renouf & Smith, 2011; Leiserowitz & Smith, 2010; Maibach, Roser-Renouf & Leiserowitz, 2009; McCright, 2010). Available indicators suggest that the science is poorly understood and embroiled in a heated social controversy.

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<sup>2</sup> One possible explanation for this recent increase in attention to climate change education is that climate change has also recently gained considerable momentum in the natural science community. Citation analyses of peer-reviewed articles related to the physical science of climate change showed that studies increased over the past century from 1 article in 1907 to 862 in 2009, with most of this increase occurring since 1990 (Li, Wang & Ho, 2011). A back-of-the-envelope examination of an unrestricted (all disciplines, not just physical sciences) search results for “climate change” on the research database Web of Science indicates that of the over 93,000 articles related to climate change, ~30% of them were published between Jan. 2010- April 2012. Limiting this search to the 4,800 of this related to humanities and the social sciences reveals that ~ 34% of these articles were published between Jan. 2010- April 2012.

I draw on literature from a broad range of disciplines and fields (education, the science of learning, atmospheric sciences, history, communications, etc.) and sources (peer-reviewed journal articles, newspaper and magazine articles, scholarly and popular books) to describe strategies for engaging the public with climate science in the current socio-historical context. Taking a broad perspective on climate change and climate science learning recognizes that the focus for climate change educators should not only be to support students' conceptual understandings of the science, but also understandings of scientific processes, and to provide support for learners to increase their participation in making effective decisions about responding to climate change impacts. Climate change learning is currently situated in a complicated social context. To motivate the conceptual, epistemological and decision-making dimensions of climate change education, I begin with an overview of the current understanding of and attitudes toward climate science in America, and place this in a historical context of social controversy.

### **Current Understanding of Climate Change Science in America and the Development of the "Climate Change Controversy"**

For the past few decades, polling agencies such as Gallup and the Pew Research Center have attempted to describe not only the state of the American public's basic knowledge of environmental issues and climate science, but also their beliefs and attitudes toward the science (Kohut et al., 2010; Leiserowitz et al., 2011; Leiserowitz & Smith, 2010; McCright, 2010). These studies indicate a wide spectrum of public attitudes towards and knowledge of climate change, climate science, and potential climate impacts. It is important that science educators interested in supporting the teaching and learning of

climate change science attend to the complex relationship between climate science knowledge and beliefs and the persistent public perception of controversy that is the current context for climate change education.

Polls over the past decade indicate 34%-63% of Americans think that humans are influencing climate change, and that these percentages have fluctuated, but generally declined over the past decade (Kohut et al., 2010; Leiserowitz et al., 2011; Leiserowitz & Smith, 2010; McCright, 2010). In addition there is a significant portion of the population (polling ranges from 34-50%) that do not believe that global warming is happening at all, anthropogenic or not. This disagreement among the general American population is not reflected within the scientific community. The IPCC, an international, nonpartisan organization, is charged with reporting the consensus view of climate science. The Technical Summary for the IPCC's Fourth Assessment Report (AR4), a research consensus document, stated:

From new estimates of the combined anthropogenic forcing due to greenhouse gases, aerosols and land surface changes, it is *extremely likely* that human activities have exerted a substantial net warming influence on climate since 1750. (IPCC, 2007b, p. 81)

The technical summary further defines "extremely likely" as a >95% probability. Thus, there is a >95% probability that human activities ("anthropogenic forcing") has already caused a net increase in global temperatures. The IPCC AR4 further reports that the scientific consensus on future climate changes is that it is "virtually certain" (defined as >99% probability) that in the future there will be increased global temperatures. Some increase in globally averaged temperature is expected to occur whether or not human

influences continue, due to the length of time that greenhouse gases reside in the ocean and atmosphere: “Even if concentrations of radiative forcing agents were to be stabilised, further committed warming and related climate changes would be expected to occur, largely because of time lags associated with processes in the oceans” (p. 89). A recent study surveying the scientific community found that 97-99% of scientists actively researching in the field of climate and climate change science support this consensus view (Anderegg, Prall, Harold & Schneider, 2010). Despite this agreement within the scientific community, it is apparent that a public consensus on climate change has not developed in parallel to the scientific consensus.

Given that the public’s understanding of the most fundamental scientific information about climate change science (i.e. that humans can and are influencing climate) is not correlated with the growing body of scientific evidence, what, then, influences how the public understands climate? Recent work has demonstrated that concern about climate change and acceptance of the scientific consensus of anthropogenic climate change is closely related to political party affiliation (Leiserowitz et al., 2011; Leiserowitz & Smith, 2010; McCright, 2010). Individuals who identify as Liberal or Democrat are more likely to support the scientific consensus than those that identify as Conservative or Republican. This polarization has grown throughout the past decade. Interestingly, level of educational attainment is positively correlated with supporting the scientific consensus among Democrats, but weakly or negatively correlated for Republicans. That is, a college educated Democrat is *more* likely to accept the scientific consensus than a non-college educated Democrat; whereas a college educated Republican is generally *less* likely to accept the scientific consensus than a non-college educated Republican (McCright, 2010).

Leiserowitz & Smith (2010) also explored this relationship between scientific understanding and concern about climate change using the Six Americas framework, in which Americans are segmented into groups depending on their perceptions of and attitudes toward climate change: Alarmed, Concerned, Cautious, Disengaged, Doubtful and Dismissive (Maibach et al., 2009). While those in the Alarmed group were in general more able to correctly answer questions about scientific content than their counterparts in other groups, they were also more likely to make errors in over-identifying sources of climate change (e.g. inappropriately identify toxic waste or depletion of stratospheric ozone as contributing to current climate change). While individuals in the Dismissive group in general had the lowest scores on answering conceptual questions, as a group they were better able to identify the greenhouse effect as resulting from gases that absorb and reemit heat in the atmosphere than the Alarmed group. However, they overwhelmingly underestimated the greenhouse effect's ability to change earth's temperature.

One striking result from the Six Americas studies is that the idea that there is scientific controversy about anthropogenic climate change is alive and well among much of the American population. Even 23% of the Alarmed group reported that they thought there was a great deal of disagreement among scientists as to the causes of global warming. The other groups reported an even higher perception of controversy amongst scientists, with an overwhelming 92% of the Dismissive believing that there is either a large amount to disagreement among scientists (76%) or that most scientists believe global warming is not happening (16%) (Leiserowitz et al., 2011). What are the origins of the belief in a scientific controversy over climate change, and how has this belief in controversy survived despite the overwhelming agreement amongst scientists?

Despite the fact that climate change has only recently been gaining momentum in the public arena, scientists have understood the mechanisms of carbon dioxide-induced atmospheric warming for over 150 years. From John Tyndall in the 1850s discovering that atmospheric gases could absorb heat, to Charles Keeling and Roger Revelle measuring atmospheric CO<sub>2</sub> and temperature in the 1950s (a time-series record known as the “Keeling Curve”) climate science has a long scientific history. From the middle of the twentieth century on, climate scientists have only become more certain of the causes of global warming, as described in the four IPCC consensus reports (IPCC, 2007a, b).

If the controversy is not stemming from the basic physics of climate or the climate scientists, then, where does it come from? In *Merchants of Doubt*, Naomi Oreskes & Erik Conway (2010) provide a historical argument that implicates particular high-profile scientists as encouraging the climate controversy using what they call the Tobacco Strategy. These scientists, argue Oreskes & Conway, are the same ones who produced pro-Tobacco science in the 1960s, and also produced misleading reports about the science behind the ozone hole and acid rain. Notably, these scientists are mostly physicists; none are climate scientists.

Oreskes & Conway contend that reports from these scientists misled or misrepresented science in order to delay a government response to warming. This was possible in part because, due to the ocean’s ability to absorb heat, an atmospheric temperature increase due to anthropogenic activities wasn’t expected to occur for up to fifty years after the emission of CO<sub>2</sub>. Thus, policy-makers were faced with having to make (or fail to make) decisions before they could see the impact of the changes. Unfortunately, by the time changes would be seen, it would be far too late to prevent negative impacts. It

is perhaps not surprising that an organization of high-profile scientists providing alternative mechanisms for warming (such as changes in solar radiation) or even hinting at a possible global cooling, would be attractive to policy-makers. Thus, this movement challenging the scientific consensus was born with strong ties to both highly-educated populations and political conservatives, ties that are still in evidence today.

Recently, fuel was added to this public controversy during the “Climategate scandal” in which emails from British climate scientists containing disparaging remarks about climate contrarians<sup>3</sup> as well as indications of possible scientific fraud were leaked (Revkin, 2009). Though external assessors have demonstrated that the scientific data were not in fact fraudulent, the integrity of climate science became a topic of discussion on Internet and television media and news. Studies investigating where Americans get their scientific information indicate that television is the most common source, followed by Internet and newspapers (Science and Engineering Indicators, 2010). The perpetuation of the idea of a controversy in these media sources during Climategate is likely to confuse or mislead those who are looking to learn more about the science, and will reinforce the perception of controversy (Zhao, 2009).

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<sup>3</sup> People who reject the scientific consensus of anthropogenic climate change are alternately called climate *skeptics*, *deniers* and *contrarians*. All three of these terms are problematic (see discussion in O’Neill & Boykoff, 2010). Scientists take issue with *skeptics* because scientists are themselves trained to be skeptical. *Denier* is equally problematic because it evokes a moral or belief-based perspective. Additionally both *skeptic* and *denier* fail to differentiate between individuals who are actively arguing against climate change, and those who require more information before making up their minds. Finally, *contrarian* generally refers to someone with a higher level of scientific content knowledge who is actively arguing with the science. None of these terms are ideal, but for ease of reading I will refer to scientists who oppose the scientific consensus as “contrarian” and use “denier” to refer only to individuals who are aware of the scientific consensus view but, for whatever reason, reject it.

Given this context of confusion over the existence of a controversy as well as uncertainty among the public about what aspects of the climate are and are not well understood, it seems especially important for attention to be paid to climate science learning that addresses basic questions of knowledge construction within the scientific community. Developing a firmer picture of how scientists work collaboratively to produce scientific information, what uncertainty in science is, how it is evaluated, and the level of certainty associated with particular ideas, will allow individuals to evaluate and use climate-relevant information from both within and outside of the climate science community.

### **Epistemological Dimensions**

Scientific knowledge has a particular character that distinguishes it from other kinds of knowledge (e.g. Knorr Cetina, 1999; Latour and Woolgar, 1986). The characteristics of scientific knowledge that distinguish it from other ways of knowing arise from the processes by which the scientific community constructs this knowledge (Latour & Woolgar, 1986; Latour, 1987). Latour and Woolgar (1986) describe the social processes through which scientists make sense of scientific data in the construction of scientific knowledge: “Construction refers to the slow, practical craftwork by which inscriptions are superimposed and accounts backed up or dismissed” (p. 236). They outline a process for construction of facts during which scientific statements move from being conjecture or speculation to implicit fact. This transformation process occurs through social processing of these statements as scientists perform “operations” on them, such as citing, enhancing,

borrowing, and qualifying. A goal of scientists' work is to persuade the scientific community to transform statements into fact (p. 79-88).

One key characteristic of scientific knowledge is that it is held to be *objective*. A truism in the practice of science is that experiments should be repeatable by anyone, anywhere. Practicing scientists, however, recognize that this objective ideal is improbable, at best. Latour & Woolgar (1986) argue that the idea of objectivity is built into the very process of constructing scientific knowledge through these operations, arguing that: "The result of the construction of a fact is that it appears unconstructed by anyone" (p. 240). Latour's analysis informs the distinction between scientific knowledge and everyday opinions or ideas. From a scientist's perspective, the construction of the statement: "Human activities are influencing global climate" into an implicit fact represents an enormous investment of time, money and labor that relied on collaborative consensus-work by the community. Many scientists have collaboratively operated upon that statement in ways designed to remove subjective elements. There is, then, a tension in comparing knowledge constructed within the scientific community to other kinds of knowledge.<sup>4</sup>

Stephen Hilgartner (2000) also explores the issue of scientific objectivity in *Science on Stage: Expert Advice as Public Drama*. Inspired by a dramaturgical perspective of society as put forth by Erving Goffman, Hilgartner uses a conceptual framework of theatrical

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<sup>4</sup> My concern in this section is in distinguishing scientific knowledge, as described by Latour & Woolgar (1987) from less robustly-constructed knowledge that misconstrues or decontextualizes the scientific understanding, *not* in distinguishing it from other rich and robust bodies of knowledge. Privileging of scientifically constructed knowledge is problematic for multiple reasons, in that it reinforces existing power structures and devalues the deep and relevant bodies of knowledge from outside the scientific community, for example, as is especially relevant when thinking about climate change impacts, those of indigenous communities (e.g. Aikenhead, 1996; Bang & Medin, 2010; Cajete, 1994).

performance to examine how science advice plays out in the public domain. Specifically, he examines how three National Academies of Science reports on diet, nutrition and health became the subject of controversy in the 1980s. In Academies reports, he argues, there are activities that occur both “front stage” (actively displayed performances that define the public identity) and “back stage” (negotiation and processes that happen outside of the public eye). He compares the information control achieved by the Academies for a published 1982 report on diet to that of a 1985 report draft that was buried in controversy and never published. He attributes ultimate fate of this 1985 draft is attributed to the leaking of back stage processes which allowed the media to create a public debate out of this report and made the report ultimately too controversial to publish.

Many of the practices involved in the construction of scientific knowledge described by Latour & Woolgar remain the purview of this back stage negotiation. When these processes are revealed to the public, as in the case of the 1985 nutrition report, the science may suddenly appear to outsiders to be unusually controversial, though to scientists these disputes are quite normal. Thus when, as happened in Climategate, the public bears witness to decidedly non-objective comments and data processing on the part of climate scientists, credibility of the scientific community is understandably called into question. For better or for worse, given the debate that already surrounds climate change and the issues of scientific credibility that are at play, keeping the backstage completely hidden is not a viable option for the climate science community at this point.

Hulme (2009) argues that one of the reasons that climate change is controversial is because “science is not doing the job we expect or want it to...we have different expectations about what science can or should tell us, or because we view the authority of

scientific knowledge in different ways” (p. 74). One of the main things we may expect science to do is to give us certainty and truth that we can use to act. Ultimately, however, this is not a “job” science can do, as disagreements are at the heart of the scientific process. According to Hume: “Science thrives on disagreement. Science can only function through questioning and challenge. It needs the oxygen of skepticism and dispute in order to flourish” (p. 75). For science learners, however, these disagreements and disputes can be confusing, whether front-stage or back-stage.

Science education has struggled to adequately prepare students to understand and participate in these scientific disagreements. Traditionally scientific processes have been distilled into a single “scientific method” supposedly employed by scientists (Lederman, 2004; Rudolph, 2005). Rudolph (2005) outlines the historical influence of high-profile scientists in introducing laboratory practices to the science classroom, a pedagogical movement that was intended to involve students in authentic scientific practices, similar to many efforts today. Unfortunately, this eventually led to a reinforcement of the so-called “Scientific Method,” which has been used to teach a streamlined and woefully inaccurate representation of scientific process to generations of science students since.

The essentialist “Scientific Method” view of science fails to appreciate the complex, disciplinary-specific, socially-situated practices of scientists (Knorr Cetina, 1999; Latour & Woolgar, 1986; Traweek, 1992). This Scientific Method consists of experimentation and Boolean hypotheses, two characteristics that are notably absent in much of the field- or model-based climate change research. To promote a more sophisticated understanding of climate scientists’ work will support individuals in evaluating and using the large body of scientifically constructed knowledge.

Recent consensus reports on science learning include reflecting on the scientific enterprise and engaging in collaborative scientific practices as important dimensions of science learning (NRC, 2007; 2009); the Framework for K-12 Science Education and the draft of Next Generation Science Standards(NRC, 2011; NGSS, 2012) includes scientific practices as one of three dimensions of the framework. In Table 1, I outline three guiding questions concerning epistemological dimensions of climate change science. I then suggest a series of learning goals associated with these questions. These goals are not meant to be exhaustive or to generalize across all learning settings. Educators are encouraged to explore these questions further and create goals that are appropriate for their own learning environments of interest.

One can use the metaphor of a pyramid when describing the body of scientific literature. The pyramid is built on a foundation of hundreds or thousands of studies that well-describe a particular phenomenon. The pyramid grows as new knowledge is created, with the studies at the top of the pyramid being the newest and the least certain. Implicit in this view of the scientific enterprise is its collaborative and cumulative nature. For an idea, such as the anthropogenic influence on climate change, to be considered a valid scientific idea it must, as Latour & Woolgar (1986) points out, be co-constructed by many members of the scientific community. To be a solid idea, it must also be evidenced in multiple arenas, i.e. if something is to be scientifically true, it must be observable in multiple ways, in order to prevent it being an artifact of observation. In climate science, then, the Keeling curve was *suggestive* of anthropogenic carbon dioxide contributing to global warming but was not, in and of itself, sufficient evidence. As multiple lines of evidence accumulated, the scientific foundation for climate change became stronger.

Climate change communication researchers have also studied how climate change is communicated by scientists and in the media as potential factors in propagating confusion around scientific epistemology, and uncertainty in particular. The impression of an uncertain science is perhaps bolstered by scientists' propensity to talk about the uncertain aspects of science (Nisbet, 2003) or by journalistic norms that govern treatment of the science in the media (Boykoff & Boykoff, 2007). From a science communication standpoint,

Table 1: Epistemological dimensions of climate change learning

<b>Epistemological Dimensions</b>	
<b>Question 1: Where does scientific information come from?</b>	Learners should... <ol style="list-style-type: none"> <li>a. Understand the process by which scientific ideas become accepted scientific knowledge as a collaborative one, and understand that multiple studies by multiple groups of scientists are required for an idea to gain acceptance within the scientific community</li> <li>b. Understand the formal and informal critical review processes by which scientists critique each others' work</li> </ol>
<b>Question 2: What is uncertainty in science? What is the process by which scientists evaluate what is uncertain and what is well-understood?</b>	Learners should... <ol style="list-style-type: none"> <li>a. Understand scientific <i>uncertainty</i> as a measure of a scientists' confidence in a given experimental result, and understand why scientific experimentation inherently has associated uncertainty.</li> <li>b. Distinguish between the aspects of climate science that are well understood (e.g. the mechanism of the greenhouse effect on temperature) and those that are not as well understood and have greater uncertainty (e.g. the magnitude of cloud feedbacks on global temperature).</li> <li>c. Understand that the scientific consensus opinion on climate change has developed over time based on multiple lines of evidence that demonstrate that climate is changing, and will continue to change, and that the changes are caused by human activities</li> </ol>
<b>Question 3. What makes a source scientifically</b>	Learners should... <ol style="list-style-type: none"> <li>a. Evaluate whether or not a source is scientifically credible based on its source (for example an established journal versus a personal</li> </ol>

<b>credible?</b>	<p>website), peer-review status, cited references, and funding sources.</p> <p>b. Construct, recognize and critique arguments using scientific evidence.</p> <p>c. Distinguish scientific evidence from other forms of evidence.</p> <p>d. Know how to find and utilize scientific documents from primary sources (such as the IPCC assessment reports) and credible secondary sources (such as the climate science website <a href="http://realclimate.org">realclimate.org</a>) to learn about climate science.</p>
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it is important that the public understands that there are, in fact, some areas of the science that are very well understood while others are more active areas of debate and research. Many of the most fundamental of these well-understood ideas are detailed in the conceptual learning goals section.

One further challenge is that though the IPCC reports include explicit explanations of where the uncertainties in the science come from and how to interpret them, these definitions are not widely known outside of the scientific community. Budescu, Broomell & Por (2009) found that when given sentences from the IPCC report to read, individuals' judgment of statistical probability was lower than IPCC intended. That is, participants underestimated the level of certainty of the science given the IPCC's language.

While understanding the uncertainty and scope of the current understanding of climate change is important, learners will also need to be able to find and evaluate the credibility of new information. Researchers have described our current society as part of an "information age," where the magnitude and immediate access to information is greater than at any point in history (Collins & Halverson, 2009). This has caused a shift from the traditional notion of an expert as an encyclopedic source of all knowledge on a given topic, to that of an adaptive expert, or expert learner. An adaptive expert is able to locate and use information relevant to solving problems and answering questions as they arise. While it is

unrealistic to assume that the general public will *en masse* become adaptive experts in climate change or climate science, this notion of adaptive expertise or just-in-time learning is relevant to promoting contemporary science learning. Since contemporary science is constantly evolving, and sources of information such as the Internet are crowded with conflicting messages, it is necessary for learners to be able to identify which sources of information are scientifically credible. One difficulty is that the majority of scientific information produced directly by the scientific community is not written in a way that is accessible to a general audience, and a growing body of literature addresses the improvement of climate change communication and the crafting of effective messages (Fischhoff, 2007; McBean & Hengeveld, 2010; Nerlich, Koteyko & Brown, 2010; Risbey, 2008; Somerville, 2011). It is important, then, to both create new materials that are accessible to those outside of the scientific community, and to support the teaching of discernment of sources of information, helping individuals evaluate the origins, perspectives and biases of the sources that they choose to use.

### **Conceptual Dimensions**

So far, this discussion of climate science learning has concentrated mainly on issues related to processes of climate science knowledge production and public communication. However, as is the case with all science learning, one cannot ignore the paramount importance of a conceptual understanding of the science. For those members of the public who are or will become engaged in climate-related activities and decisions in their everyday lives, it is important that they are able to base their work on accurate ideas of the climate system. In addition, having a well-developed model of the climate system as we

currently understand it will help learners integrate new information into their understanding of climate as the information becomes available.

Before establishing what we think the public *should* know, it is useful to quickly review what the current public understanding of climate already is. In the polling data discussed above, roughly 50% of the public accepted the scientific consensus and 50% did not. However, there are a variety of important climate concepts in addition to anthropogenesis that are important in order to respond to climate change impacts. In the survey by Leiserowitz & Smith (2010), respondents were asked to determine the veracity of conceptual statements. Content areas ranged from sources of CO<sub>2</sub>, sources of energy from fossil fuels and types of fossil fuels, to past climate change, conceptual models of the climate system and predicted climate. Given that their analysis is focused on examining climate literacy among particular audience segments, it is hard to use this data to extrapolate any general patterns of understanding across the entire population. What is notable, however, is that in the grading of the survey, over half of the respondents received a grade of D (23-43% correct) or F (<22%); in other words, most respondents failed the test. This poor showing may be due in part to the fact that Leiserowitz & Smith's survey was extremely detailed, going beyond what is normally presented in the media. The learning goals reported here are less exhaustive than Leiserowitz & Smith's survey, but still go beyond the attribution of the causes of current climate changes.

In defining conceptual learning goals, I have drawn on multiple standards documents (e.g. *2009 Climate Literacy standards*; NRC 2010; "A Framework for K-12 Science Education," 2011; "Benchmarks Online- Project 2061- AAAS," n.d.; "Climate Literacy: The essential Principles of Climate Sciences," 2009; "Washington State K-12

Science Learning Standards,” 2009). In addition, I have taken into consideration the thoughts of climate scientists, both from published articles (e.g. Somerville, 2010, “Understanding and Responding to Climate Change,” 2008) and personal conversation. However, unlike the majority of these documents that present concepts as unrelated bullet-points, I have attempted to organize these learning goals in a way that emphasizes the interconnected, systemic workings of the climate. More information on all of these learning goals can be found in the IPCC AR4 report (IPCC, 2007).

In order to understand the sometimes-surprising responses of the climate system to different forcings, it is vital to have an understanding of the climate as a *system*, not as a series of linear or disconnected binary relationships. This understanding of climate as a system is not only in keeping with the scientific workings of the climate science community, it also has a deep synergy with ecological epistemological models, including non-dominant cultural epistemologies that are underrepresented in science education (for a discussion of cultural epistemologies in relation to science education, see Bang, Medin & Atran, 2007; Bang & Medin, 2010). I therefore emphasize the implications of the interrelated nature of the climate. I attempt to highlight key anthropogenic impacts while not artificially separating humans from the other elements of the system. As with the epistemological learning goals, I have arranged these in Table 2 under a series of questions—five in this case—that highlight key ideas: systems, mechanisms of change, timescales, sources of data, and climate impacts.

One aspect of climate science that can be an advantage in conceptual learning of climate is that all learners will already have personal experiences with the workings of the climate system. In our everyday lives, we are influenced by changes in weather on short

time scales, and changes in climate (such as the multi-year California drought) on longer time scales. In addition, we have some understanding of regional climate variability.

However, given the complexity of the climate system, these initial experiences with climate-related phenomena provide an incomplete and potentially misleading picture of how the system actually works.

Table 2: Conceptual dimensions of climate change learning

<b>Conceptual Dimensions</b>	
<b>Question 1. What is the climate system?</b>	<ul style="list-style-type: none"> <li>a. The <i>climate</i> is a complex set of interactions that transfer energy throughout the earth system. <i>Climate</i> refers to averaged process of this system over long time-scales, such as years, months or seasons. <i>Weather</i> refers to variability on shorter time-scales, such as minutes or days.</li> <li>b. Important components of the climate system include the sun, atmospheric gases such as water vapor and carbon dioxide, aerosols and clouds, and the oceans.</li> <li>c. Components of the climate system are interconnected such that influencing one component will cause changes throughout the rest of the system. These processes are called <i>feedbacks</i>. Feedbacks may cause temperature changes to be greater than (a positive feedback), or less than (a negative feedback) what would be expected in a system without feedbacks.</li> </ul>
<b>Question 2. What causes climate to change?</b>	<ul style="list-style-type: none"> <li>a. Humans are currently influencing climate, primarily through activities such as the burning of fossil fuels that emit greenhouse gases such as CO<sub>2</sub> or methane (CH<sub>4</sub>).</li> <li>b. The climate system also varies naturally. Historical records of natural climate variability over the past 800,000 years suggest that much of the variability during this time period well correlated to changes in the earth positioning with respect to the sun over long time scales. Mechanisms of natural climate variability do not explain the current climate changes.</li> </ul>
<b>Question 3. How long does it take for</b>	<ul style="list-style-type: none"> <li>a. Climate changes occur on many timescales. For example, for the past 800,000 years, an ice age has occurred every 100,000 years.</li> <li>b. Climate changes caused by human activities are already apparent.</li> </ul>

<p><b>climate to change?</b></p>	<p>Global climate is projected to be significantly different from today's climate by 2100. This is a much faster timescale of change than most historical climate changes.</p> <p>c. CO<sub>2</sub> in the atmosphere continues to affect climate for 1000 years after it is emitted. Thus, climate changes are expected to be long-term-- once CO<sub>2</sub> enters the atmosphere, we are "committed" to climate change from that CO<sub>2</sub> for 1000 years, barring manual removal of the CO<sub>2</sub>.</p>
<p><b>Question 4.</b>  <b>How do scientists study climate change?</b>  <b>What do climate predictions mean?</b></p>	<p>a. Scientists describe and observe climate components, create theoretical understandings of these components, and construct global climate models to understand the climate system and predict the changes that will result from perturbations to the system.</p> <p>b. Global climate models are complex quantitative models that run on sophisticated computers. They are designed to calculate responses of the climate system given a set of values for the various components, and are informed by observations of climate phenomena. Climate predictions such as an increase in average global temperature of 3-10°C by the year 2100 are the results of these models, and the range in predictions is due in part to differences between models and varying emissions scenarios. As our ability to model interactions improve, these ranges may decrease.</p>
<p><b>Question 5.</b>  <b>What climate changes will likely occur as a result of human activities?</b></p>	<p>a. Increased globally averaged temperatures, increase in severe weather events, changes in precipitation, and sea level rise from melting of polar ice and mid-latitude glaciers are all either expected or currently observable consequences of climate change.</p> <p>b. Carbon dioxide changes ocean chemistry, acidifying the water with consequences for ocean ecosystems, a process called ocean acidification.</p> <p>c. Changes in the climate system will impact resource availability for humans. Resource impacts include depleting arable land, decreased water quality and availability, decreased biodiversity and loss of fisheries.</p> <p>d. Regional climate changes are variable and are not expected to follow global averages. Both temperature and precipitation changes will vary geographically, with the general pattern of rainier places becoming rainier, and drier places becoming drier.</p>

Literature on how people learn concepts underscores the importance of the existing knowledge and prior experiences that learners bring to a new situation, in that learners make sense of new information in the context of what they already know (e.g. Bransford et al. 2000; diSessa, 2006). This may result in understandings that, while coherent to the learner, do not accurately represent the concept. For example, hearing about global warming, an individual may connect this to the ozone hole which they also know can cause warming, even though these two mechanisms of warming are unrelated (Cordero, 2008; Leiserowitz & Smith, 2010).

In addition to the American public survey studies conducted by Leiserowitz & Smith (2010), some studies have focused on K-16 student conceptual understandings (Jakobsson et al., 2009; Jeffries, Stanisstreet, & Boyes, 2001; Shepardson et al., 2010). In a study of junior high and high school students, Shepardson et al. (2010) examined student conceptions of global warming prior to any instruction by their current teachers on the subject in an effort to understand student preconceptions. One noteworthy finding of this study is a general belief that anthropogenic climate change will have no impact on students' everyday life. This common preconception, perhaps due in part to the multi-year timescales of change and regional variability in climate and weather, is indicative of an inaccurate conceptual understanding of the interactions of the climate system. Specifically, it places everyday human functioning outside of the rest of the climate system, as opposed to a systemic epistemological model in which humans are inherently inseparable from the whole. While epistemological models that have this holistic and ecological view are important in understanding the connections in the climate system, they are not traditionally the focus of science education (Bang, Medin & Atran, 2007). Being attuned to

the conceptions of climate and the epistemological models that the public currently has will help educators help individuals learn the complex climate concepts.

### **Decision-Making Dimensions**

Perhaps the most common question among individuals who worry about changing climate—regardless of their level of epistemological or conceptual understanding of the science—is: What can I do? Unfortunately, the answer to this question is often either rather vague or an overwhelming constellation of behavioral changes. In addition, many of these behavioral changes, such as using fuel-efficient vehicles and energy-efficient appliances, buying local and organic foods, etc., carry high price-tags that many Americans cannot afford, especially in the current economic climate.

A National Academies of Science Report on responding to climate change addresses the inequity inherent in climate change impacts, that those who are most impacted by climate will have the most difficulty adapting to climate:

Climate change will affect ecosystems and human systems—such as agricultural, transportation, and health infrastructure—in ways we are only beginning to understand. ... In general, the larger and faster the changes in climate are, the more difficult it will be for human and natural systems to adapt. Unfortunately, the regions that will be most severely affected are often the regions that are the least able to adapt. Bangladesh, one of the poorest nations in the world, is projected to lose 17.5 percent of its land if sea level rises about 1 meter (39 inches), displacing millions of people. Several islands in the South Pacific and Indian oceans may disappear. Many other coastal regions will be at increased risk of flooding, especially

during storm surges, threatening animals, plants, and human infrastructure such as roads, bridges, and water supplies. (p. 16-17)

This disparity in responsibility for and adaptability to a changing climate make it ultimately a social justice issue, with implications far outside the scientific community (e.g. Thomas and Twyman, 2005). In order to make choices that will have the greatest positive societal impact, it is important that all communities, not just scientific ones, are educated about climate change science and climate impacts. Underscoring this point, Hassan (2009) notes that human agency plays a key role in responding to climate change impacts, as human ingenuity leads communities to make adjustments that maintain community and cultural sustainability (Hassan, 2009, p.41). How, then, can we promote agency in responding to climate change?

A public that has a proficient conceptual understanding of climate change is a positive step in public participation in climate science and climate-related activities, but is not enough. It is also necessary to help individuals and communities find ways to increase their participation in effective, value-based climate solutions. The climate solutions learning goals presented in Table 3 are crafted from a scientific consensus viewpoint, and emphasize the need for climate solutions on multiple levels—individual, community and global.

Anthropologists Crate and Nutall (2009) describe climate change as ultimately an issue of culture. Due to the risks and opportunities associated with a changing climate and shifting resource availability, current global climate change challenges cultural survival. The ability of humans to adapt and respond to climate change impacts is likely to be community-specific (p. 16), and inequitable. Even in areas with sufficient resources,

responding to climate change impacts will not be easy. One of the key difficulties in responding to climate change from both an individual and a policy standpoint, is that there is no one single solution for addressing the problem of greenhouse gases emissions. This is in contrast to other environmental problems-- for example the depletion of stratospheric ozone-- that do have clear solutions. Carbon dioxide and other greenhouse gases have many sources and are entwined into our functioning as a society. Because of this, attaining a true climate solution may seem overwhelming or impossible.

Table 3: Decision-Making dimensions of climate change learning

<b>Decision-Making Dimensions</b>	
<b>Question 1. What do I value? How might climate impacts affect things I care about?</b>	<p>Learners should...</p> <ol style="list-style-type: none"> <li>Identify their own values and the values of their communities</li> <li>Investigate how climate change impacts may potentially impact the things they value.</li> <li>Use their values to guide their decision-making processes.</li> </ol>
<b>Question 1. What are characteristics of effective climate solutions?</b>	<p>Learners should...</p> <ol style="list-style-type: none"> <li>Understand the difference between response approaches that <i>mitigate</i> climate change, and those that are designed to <i>adapt</i> to climate change.</li> <li>Understand that since many human activities can have long-lived affects on climate, the need for action on climate change is urgent.</li> <li>Attend to local and community-specific needs, recognizing that because of variability in regional climate changes and impacts, effective solutions and strategies will be regionally-specific.</li> <li>Explore both individual behaviors that decrease emissions of fossil fuels and can help alleviate climate change, as well-as strategies for wide-scale legislation and regulation of carbon dioxide and other greenhouse gases that will be necessary to avoid many of the potential negative consequences of climate change.</li> <li>Evaluate the current technologies available to respond to climate change, recognizing that although there is no way to mitigate climate change using only one mechanism or process, there currently exists the technology to mitigate or adapt to climate</li> </ol>

	change by using multiple solutions.
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In a landmark paper, Pacala & Stocolow (2004) introduced the “Wedges” concept of climate solutions. They demonstrate how investing in and developing a suite of technologies can be used to reduce carbon emissions over the next hundred years. This approach overlays wedges onto the projected carbon emissions scenarios from the IPCC, and demonstrates how seven wedges are necessary in order to stabilize atmospheric carbon dioxide. Wedges can be made from various technologies for carbon capture, carbon storage and renewable energy (Pacala & Stocolow, 2004). What is powerful about this approach is that it not only reframes climate solutions as possible, but it also provides agency in decision-making—as a society we can choose which wedges/technologies we want to invest in order to solve the climate problem.

Prins & Rayner (2007) also argue that a multi-faceted approach to climate solutions is needed. They contend that climate change responses to date have failed to adequately address the difference between current climate change and past environmental crises, such as stratospheric ozone depletion and acid rain, in that unlike these past situations, there is no single “silver bullet” answer to climate change. Rather, multiple approaches are needed, an approach they term “silver buckshot”:

In the case of climate change this would mean adopting a wide variety of climate policies—silver buckshot—and non-climate policies with climate effects. Each would have the potential to tackle some part of the overall problem, although it would not be clear which would be the most successful, let alone the most economically efficient. (p. 26)

One hindrance to effective climate action is that, as Prins & Raynor (2007) state above, we don't know which actions will be the most successful, or which will be best for the economy. Citizens and policy-makers need to develop strategies that enable them to move forward with responses to climate change even if the "best" solution remains elusive.

But how do we act if we don't know what's best? Jasanoff (2007) implicates this uncertainty inherent in using science to make decisions as a stumbling block for policy-makers. She calls for "technologies of humility" that will allow policy-makers to make value-based decisions on uncertain science:

We need disciplined methods to accommodate the partiality of scientific knowledge and to act under irredeemable uncertainty. Let us call these technologies of humility. These technologies compel us to reflect on the sources of ambiguity, indeterminacy and complexity. Humility instructs us to think harder about how to reframe problems so that their ethical dimensions are brought to light, which new facts to seek and when to resist asking science for clarification. Humility directs us to alleviate known causes of peoples' vulnerability to harm, to pay attention to the distribution of risks and benefits, and to reflect on the social factors that promote or discourage learning. (p. 33)

Jasanoff argues that there is a problematic cycle in which policy-makers continually call the scientific community to reduce the uncertainty in the science instead of acting or responding in ways that attend to values and ethics. She calls uncertainty "the threat to collective action, the disease that knowledge must cure" (p. 33). The uncertainty will always be there in the science, so instead of waiting for science to give us answers it can't

give, Jasanoff calls policy-makers to “re-engage with the moral foundations for acting in the face of inevitable scientific uncertainty” (p. 33).

Responding effectively to climate change impacts will require public participation in values-based, scientifically-informed decision-making. Scientifically-based inquiry and decision-making on uncertain issues such as climate change has been termed “Post-Normal Science” (Funtowicz & Ravetz, 1993; Ravetz & Funtowicz, 1999). Like Jasanoff and Prins & Raynor, Funtowicz & Ravetz (1993) are concerned with supporting effective action the face of uncertainty:

But all the causal elements are uncertain in the extreme; to wait until all the facts are in, would be another form of imprudence. At stake may be much of the built environment and the settlement patterns of people; mass migrations from low-lying districts could be required sooner or later, with the consequent economic, social and cultural upheaval. Such far-reaching societal policies will be decided on the basis of scientific information that is inherently uncertain to an extreme degree; even more so because plans for mitigation must be started with a long lead-time so that the huge rebuilding and resettlement programmes can get under way... Public agreement and participation, deriving essentially from value commitments, will be decisive for the assessment of risks and the setting of policy. (Funtowicz & Ravetz, 1993, p. 751)

An important part of education for effective decision-making is helping learners articulate what these “value commitments” are that, integrated with scientific understandings, can guide decision-making processes.

A view of learning as “life-long, life-wide and life-deep” attends to learning that occurs throughout a lifetime, in multiple contexts and is mediated by particular religious, moral and social values (Banks et al. 2007). Learning is thus understood to be socio-culturally situated and culturally mediated across settings and communities of participation over developmental timescales. To date, many climate change communication efforts have been focused on dissemination of climate change concepts with little regard to diverse sociocultural contexts, the values and norms of diverse communities, and the developmental aspect of conceptual and epistemic knowledge. More attention should be paid to how to engage culturally diverse groups in climate science, and what opportunities and challenges there may be for engaging particular groups. This lack of attention to cultural diversity in climate change education is especially problematic when one considers that in the Six America’s audience segmentation analysis, the one labeled “Disengaged” is the only category where individuals are more likely than average to be an ethnic minority, and only one of two categories (the other being “Alarmed”) where individuals are more likely to be women (Maibach et al., 2009). This group is also more likely to live in higher poverty areas. The Disengaged group is characterized by generally not knowing much about or acting on climate change issues. Given that diversity has not consistently been a priority for climate change educators, perhaps this group would be better identified as “*not* engaged” or “ignored.” It is necessary for climate change educators to be increasingly cognizant of engaging learners with a diversity of backgrounds, so that these voices can bring their values, knowledge and experience to the conversation. Setting aside issues of gender and ethnicity, engaging low-income communities in climate education is especially imperative since, as described earlier, impacts of climate change are

generally predicted be more severe for high-poverty areas who will have a harder time adjusting to depleted resources, as discussed in more detail in the next section (IPCC, 2007; NAS, 2008). Making sure that *all* voices are heard and *all* individuals have the opportunity to participate in climate solutions activities is ultimately a social justice issue and should be a top priority for educators.

Making effective decisions and sustaining mitigation and adaption strategies is complex, as it requires learners to not only connect their own actions to consequences for the climate, but also to change behavior patterns. Research has explored challenges and strategies for promoting sustainable action related to climate change. For example, Cordero (2008) demonstrated that a Carbon Footprint calculator helped students recognize how actions in their own lives connected to the conceptual understandings of climate change. McMillan (2004) found that using a Carbon Footprint calculator deepened students' environmental values. However, even with changing values and an understanding of what actions are necessary, individuals struggle to maintain behavioral changes (Woodside, 2011). More research is needed to understand how best to support participants' decision-making and sustainable behavior changes.

While the complexity of climate solutions does represent a challenge, I would argue that it also provides certain advantages. First, though climate change is global problem, it will present differently across communities and geographic regions. This provides abundant opportunity for educators to customize climate change education in ways that are relevant to their particular community of learners. Instead of trying to present a picture of all possible actions and behavioral changes, educators can focus on those actions and decisions that will allow learners to have the greatest impact on and relevance to their

community. Because of the wide range of avenues for participation in climate solutions, educators can choose to engage learners with those that will be interesting and applicable to their audience.

Another benefit of the complexity of the climate system is that there is an entry point into the discussion of climate change from nearly every other field. Interests in economics, philosophy, religion, policy, education, art, etc. can all be leveraged in a discussion around climate change, and many different skills will be needed in order to achieve effective climate solutions. Several programs have had success in tailoring climate education to the specific needs of their communities. The National Wildlife Foundation targeted conservative groups characteristic of the “Dismissive” population in rural areas that didn’t accept the scientific consensus of climate change. By engaging hunters and anglers in climate impacts within the context of valued activities and environments, they were able to successfully activate them for conservation and mitigation efforts (Coyle, 2010). Interfaith Power and Light, a multi-faith environmental conservation organization, has also targeted climate education to particular audiences. They found that messages of environmental stewardship and social justice, particularly when tied to faith-specific doctrine, are the most successful in engaging faith communities (Hitzhusen, 2010). Thus, the initially overwhelming complexity of climate solutions can serve as an entry-point for broadening participation in personally relevant climate change science and activities.

## **Conclusion**

Tackling the challenges that arise from climate change will arguably be one of the most important scientific and societal undertakings of the 21<sup>st</sup> century. How we as

individuals, communities and nations choose to engage with a changing climate will have consequences for generations living a thousand years from now. Over the past fifty years, public controversy about climate change created a challenging social context for learning about and responding to climate change. Learners' engagement with climate science is inherently intertwined with political, cultural and personal values, and prior experiences with both science and the climate.

This chapter provides a foundation for defining and focusing the aims of the curriculum described in the rest of this dissertation, and the broader social context in which learning took place for the students who participate in these curricula. In this dissertation I view climate change science as ultimately an exciting opportunity to engage the public in contemporary, personally-relevant science. The ongoing work of climate scientists to develop a better understanding of our climate, of the impacts of human activities on climate, and of climate change impacts on human activities can be used as an example of how scientific facts are constructed. Climate science concepts, practices and impacts can be connected to other areas of interest in people's lives. A public that is proficient in climate science will be able to make scientifically informed decisions in their everyday lives that will be in line with their personal and national values. It is our responsibility as educators to engage the public in this important science in the years to come, and the aim of this dissertation is to contribute to that effort.

## Chapter 2

### **“Thank you for being Republican”: Case studies of high school students negotiating political ideologies and scientific evidence for climate change<sup>5</sup>**

#### **Introduction**

*“Now comes the threat of climate crisis – a threat that is real, rising, imminent, and universal. Once again, it is the 11th hour. The penalties for ignoring this challenge are immense and growing, and at some near point would be unsustainable and unrecoverable. For now we still have the power to choose our fate, and the remaining question is only this: Have we the will to act vigorously and in time, or will we remain imprisoned by a dangerous illusion?” – Al Gore, Nobel Lecture, 2007*

*“Like global warming. You could establish multiple times a day the hoax this is. Have they stopped? Have they stopped trying to implement everything that they were doing because of global warming, even though it's been established? And, by the way, how do they do that? How do they do that? It's a giant guilt trip. They come at you, all these global warming people, ‘You have caused this massive destruction of our planet.’ Then they offer you redemption: agree to higher taxes; agree to limit your travels to wildlife; agree to drive different cars, and you can redeem yourself, and you can win the approval of the state if you do the right thing to save the planet.” – Rush Limbaugh, The Rush Limbaugh Show, 2012*

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<sup>5</sup> I would like to acknowledge Dr. Blakely Tsurusaki, the other researcher on this project. While the analysis presented in this dissertation has to this point been written by myself alone, it owes a great debt to Dr. Tsurusaki’s invaluable insight and guidance, and any future publication of this analysis will be jointly authored by Dr. Tsurusaki and myself.

Whether catching up on The Daily Show online, tuning into Fox News, or listening to NPR or The Rush Limbaugh Show, one is likely to encounter stories and opinions about global warming and climate change. From green jobs to local food, issues of carbon dioxide emissions have become increasingly foregrounded in American media. It's not only news outlets that reference climate change—climate change has surfaced in popular television shows, movies and literature. As varied as these sources of information are, so are their messages. Some support a scientific understanding of the consensus view on climate change and some do not. Others are more concerned with particular behaviors or actions. In this chapter, I explore the learning pathways of five high school students navigating this context of social controversy during a pilot study of a unit on the ecological impacts of climate change. These students had initial perceptions of climate change informed by the messages they heard from the media and their families—both supporting and rejecting the scientific consensus—that influenced how the students engaged with the scientific evidence.

Given the conflicting messages present in the media regarding climate change, it is unsurprising that the American public has widely varying attitudes toward and perceptions of climate change. According to the Six Americas audience segmentation report, there are six main orientations to climate change: Alarmed, Concerned, Cautious, Disengaged, Doubtful and Dismissive (Maibach, et al., 2009). These groups represent a wide spectrum of attitudes, from the Alarmed who accept scientific consensus of human-influenced, or anthropogenic, climate change and are already taking action to address climate change in their own lives to the Dismissive who don't accept the scientific consensus and may believe, like Rush Limbaugh, that climate change is a conspiracy or hoax.

The acceptance of anthropogenic climate change across the Six Americas is politically polarized (Leiserowitz et al., 2011; Kohut et al., 2010; McCright, 2010; Leiserowitz & Smith, 2010). Individuals who are more concerned about global warming and who accept the scientific consensus (the Alarmed and Concerned) are more likely to be moderate or liberal and identify as Democrats while those who are least concerned about global warming and do not accept the consensus (the Doubtful and Dismissive) are more likely to be conservative and Republican. This polarization has grown significantly throughout the past decade (McCright, 2010). Furthermore, the level of educational attainment is positively correlated to support of the scientific consensus among Democrats, but weakly or negatively correlated for Republicans (McCright, 2010). This suggests that political ideologies have an influence on how individuals perceive and understand the scientific evidence.

Nisbet et al. (2010) examines the messages within the social context of climate change education using the idea of *frames* that are strategically used in climate change communication. Frames are used to organize the central ideas of an issue, highlighting or minimizing aspects of the topic and, for climate change, they are frequently related to political groups or ideologies. Those opposed to anthropogenic climate change, for example, may frame the issue by emphasizing uncertainty in the science or, as Rush Limbaugh does in the above quote, presenting climate change as a hoax or a conspiracy. Proponents of anthropogenic climate change respond to this framing by using, as Al Gore does, the counter-framing of a “climate crisis,” highlighting ideas of human devastation and biological extinction (p. 57). There is disagreement among proponents of climate science as to the validity and effectiveness of using particular frames, with some criticizing frames

used by climate change proponents as overly dramatic or “alarmist,” while others argue that their “alarming” nature is justified by the science (cf. Hulme, 2006; Risbey, 2008). These frames affect the information that is communicated and how it is presented to and perceived by audiences.

Even without a social context of controversy, understanding the scientific evidence for human-influenced climate change is in itself no small undertaking. Even someone eager to understand the scientific consensus view may have difficulty locating credible information, or may be daunted by an interdisciplinary and conceptual complex science that relies on new and unfamiliar scientific technologies and methods.

Despite its difficulties, it is necessary to prepare students to participate in responding to climate change. Bell (2004) suggests that scientific controversies provide opportunities for science education in that they exist at “the intersection of science, technology and society,” allow students to develop critical argumentation skills, deal with socially or politically relevant topics, and develop an “integrated understanding of scientific issues across the numerous contexts in which they experience them—in the classroom, on television and radio, in print media, on the Web, and in conversation” (p. 234-235). Teaching climate change science may allow students to not only increase their proficiency in important scientific practices, but also develop a greater understanding of how science is intertwined with important societal concerns.

This study explores these challenges and opportunities of climate change education in a high school classroom. I present case studies of five high school students that describe their attitudes towards, perceptions of and understandings of climate change, with particular attention to the role of political belief systems in student reasoning about

scientific evidence for climate change. These case studies illustrate that there is much more to climate science education than climate science. Educators need to attend to students' political and other ideological belief systems when supporting student's scientific understandings of climate change.

## **Theoretical Framework**

### *Learning as a cultural phenomenon*

In this study, I am concerned not only with *what* students know, but how students use particular kinds knowledge to participate in particular contexts. From a Vygotskian perspective, the development of an individual's mental functioning is ultimately mediated by participation in cultural groups (Vygotsky, 1987). Sociocultural theorists have suggested that learning should be understood as changing participation in cultural practices (Gutiérrez & Rogoff, 2003; Rogoff, 2003) or deepening participation in the practices of a community (Lave & Wenger, 1991; Wenger, 1998). These sociocultural views of learning emphasize its situated, active nature. For example, Lave (1988) espouses a view of cognition in action. This viewpoint implies that knowledge exists not in isolation, but is rather situated and best assessed through participation in particular contexts. These contexts for learning are not limited to those that are traditionally understood as formal learning environments, i.e. schools or after-school programs. Rather, a conception of learning as "life-long, life-wide and life-deep" attends to learning that occurs throughout a lifetime, across the multiple contexts of our lives, and is mediated by particular religious, moral and social values (Banks et al. 2007).

When an individual participates in multiple communities, or is on a trajectory of increasing participation in a new community, that individual must navigate participation between the practices, traditions and values of multiple communities, which may at times be at odds (e.g. Aikenhead, 1996; Banks et al., 2007; Nasir, Rosebery, Warren & Lee, 2006). Previous work has explored how individual's participation varies across various settings that privilege different systems of competency and 'kinds of persons' associated with the cultural activities (e.g. Baines, Bell & Peck, in prep; Bricker & Bell, in prep; Jackson, 2011; Nasir, 2002).

Learning not only entails what we know and do within these communities, but how these relate to who we are, what Packer (2000) describes as the ontological dimensions of learning. For Wenger (1998), who we are, i.e. our identity, is connected to practice: "a layering of events of participation and reification by which our experience and its social interpretation inform each other" (p. 151). Our identity is dependent on how we interpret experiences, define ourselves in relation to others, and by our trajectory of experience. Identity is affected by our participation in multiple communities. Wenger describes this as a "nexus of multimembership" in which some community memberships are central to our identities and some are less important (p. 158). For Wenger, identity is informed by how we reconcile these memberships that may, at times, be in tension with each other.

Lemke (2000) uses a dynamical theory of complex systems to analyze identities as occurring as ecosocial processes on multiple timescales. Lemke adds the dimension of time to considerations of participation within communities, placing "personal identity" at the nexus of interactions across multiple timescales:

Thus “personal identity” may not be as long term a phenomenon as we imagine.

Like most everything else, it too requires integration across timescales: across who we are in this event and that, at this moment or the other, with this person or another, in one role and situation or another. (p. 13)

In Lemke’s analysis, the trajectory of development of a learner’s identity is determined not only by participation in the current moment, but also by processes on longer timescales, and the artifacts that connect that longer-term identity work to the current moment. From this perspective, how a student responds to a question in class is necessarily consistent with a flexible identity that has developed over social processes on time-scales of days, years, lifetimes, and centuries.

Finally, Packer (2000) argues that epistemological and ontological aspects of learning are ultimately connected: “Our account introduces a different distinction, between epistemological and ontological aspects of human change: The former is always an aspect of the latter.” That is, how we *know* something is an aspect of who we *are*.

### *Ways of Knowing, Being & Doing*

I describe students’ trajectories through a high school climate change unit using Herrenkohl and Mertl’s (2010) framework that describes an individual’s participation in a context in terms of ways of *knowing, being and doing*. This framework is a concise way of describing an individual’s holistic and dynamic participation in social contexts. Herrenkohl and Mertl describe ways of *knowing* and *doing* as the “valued social and cultural activity” that include conceptual and epistemological dimensions of learning (p. 7). In this analysis, I use ways of knowing to describe what is known, how that knowledge is constructed from

what kinds of evidence, and what kinds of knowledge is valued. Ways of doing describe the ways individuals actively participate in particular practices. Ways of *being* are described as individual's patterns of action that arise from affective and value-laden negotiations of particular social contexts:

Ways of being include interests, motivations, emotional commitments, and personal and social values about what is worth learning and how or why one ought to put certain knowledge and skills into practice. At the most coarse grain size, ways of being are patterns of acting and speaking that identify who a person is and what she values in a specific context at a particular point in time...they emerge from and are negotiated in social interaction using culturally available tools, including ways of knowing and doing. (p. 7)

I use this framework of knowing, being and doing because it allows me to look at how students leverage particular ways that are characteristic both of the scientific and classroom practices of school as well as their family and out-of-school lives. This framework emphasizes that there are multiple ways of knowing, doing and being, and that participants negotiate these different ways of knowing, being and doing across contexts. An individual's participation in a particular moment is influenced by their current and previous involvement across the system of their participation in past contexts across timescales. Participation in other communities may have afforded an individual with particular practices or resources that could be leveraged in the current moment, or may have caused the individual to identify with particular endeavors or cultural values, or privilege particular epistemologies or ways of knowing. For example, a student entering into a high school classroom will already have a wealth of ways of knowing and doing

associated with participating in school, but will also have values, habits, knowledge and practices associated with their home or out-of-school life. This is an important consideration, as I am interested in part in looking at how what happened in a science classroom was influenced by ways of knowing, being and doing from outside the classroom.

I also use this framework because it emphasizes multiple dimensions of learning, including conceptual and epistemological ways of knowing, scientific practices and processes, and the values, motivations and interests of individual scientists and the scientific community. This approach is consistent with recent consensus reports on science learning that identify multiple strands of science learning, from conceptual understandings to identification with science (NRC, 2009).

This framework focuses on *ways of being* instead of *identity*. These conceptions are closely related. Herrenkohl and Mertl (2010) argue that the use of the term “identity” is problematic because it is associated with multiple bodies of thought and because it can potentially be seen as a static entity or an inherent property of individuals:

First, identity has become a widely used term with multiple meanings depending on author and audience (see Hicks, 1996). Second, theoretical schools that have used “identity” often give priority to either the individual or the social world but not often to the dynamic interaction that exists between them...in the literature there is a tendency to treat identities as fundamentally properties of individuals (Erikson, 1950, 1968; Harter, 1999; Marcia, 1980) or social worlds (Gergen, 1991; Goffman, 1959) rather than an interaction between individual and social world. Third, and most important for us, identity is a noun and therefore gives the impression that it is

a product or thing and not a process. Our choice of “being” allows us to emphasize a dynamic process instead of what might be misconstrued as a static product (identity or identities). (p. 8)

Like Herrenkohl and Mertl, I decided not to use “identity” in this analysis for several reasons. The students discussed in high school were in the first months of the first year in high school, a time of significant and flexible identity work; one concern I had was that using identity would underemphasize the dynamic nature of this process. In addition, this pilot study lasted only seven weeks and I didn’t feel comfortable after such a short time describing any of my participants “identities,” as I was concerned with inadvertently essentializing them. After carefully considering the data set, I decided that ways of being was a more effective way of describing the phenomena I was interested in. I attend to the identity work of the students in this analysis through the ways that students “identify” with particular groups or values in particular moments or contexts.

### *Lens of Analysis*

Herrenkohl and Mertl further describe four possible lenses for examining participation in a setting— the contextual, community, interpersonal and personal lenses. They describe the contextual lens as appropriate for examining questions related to the “standard proscriptive or idealized version of a physical and social setting and the values, principles, and practices it should espouse” (p. 20). The community and interpersonal lenses are both appropriate for looking at interactions within in a classroom— the norms and values of that classroom learning community and the “moment-to-moment interactions” between participants in that community (p. 23). Finally the personal lens examines an individual’s trajectory across situations over time, and seeks to understand

the ways of knowing, doing and being taken up by individuals within and across learning contexts.

This current analysis uses the personal lens to examine the pathways of five 9<sup>th</sup>-grade students through a seven-week unit on the ecological impacts of climate change. The focus of analysis of the personal lens is “change in individual participation over time, identifying ways of knowing and being that are nested within interpersonal, community, contextual lenses” (p. 24). Herrenkohl and Mertl describe learning trajectories as revealed through the “improvisation” of participation in ways of knowing (p.25). Thus, in looking at a particular individual, I focus first on the ways of knowing, being and doing that informed his initial understandings of and attitudes toward climate change. I then examine how these attitudes and understandings changed over time, as the student engaged in ways of knowing, being and doing connected to contextual, community and interpersonal lenses. For example, social interactions with other students, teachers or researchers in the classroom may position a student, or particular ideas about climate change in a manner that shapes that student’s pathway through the unit. In this analysis, I examine each student’s experience using the personal lens, and then tie these experiences back to the broader scope of the contextual lens.

### *Conversations: Drawing on Climate Changes’ Societal Context*

In this analysis, I am concerned not only with learners’ personal trajectories, but also with how those trajectories are tied to sociocultural and political contexts that influence understandings of and attitudes toward climate change. To aid my identification

and analysis of these broad socio-cultural influences, I draw on the idea of societal Conversations (Gee, 2011). Gee explains a capital-C Conversation in the following way:

Sometimes when we talk or write, our words don't just allude or relate to someone else's words (as in the case of intertextuality), but they allude or relate to themes, debates, or motifs that have been the focus of much talk and writing in some social group with which we are familiar or I our society as a whole. (p. 29)

Societal issues, such as smoking, climate change or the teaching of evolution in schools are the topic of "long running discussion in our society." As members of society, we are aware of the various Conversations, and of the "sides" of the debates. We can allude to these sides of the Conversation in our speech, thus referencing a larger, longer historical exchange.

There is a Conversation about climate change in our current society. The Conversation is complex, including many voices and possible identifications and touching on other societal Conversations, including politics and sustainable energy. For climate change, how this Conversation is carried out in the public arena is connected to how the participants in the Conversation frame the issue (Nisbet, 2010).

In this analysis, I use the idea of a Conversation to describe how students' participation in ways of knowing and being in the classroom aligned with aspects of the socio-cultural context for climate change learning. I examine how students referenced and participated in this Conversation throughout the unit. In addition to identifying with pieces of the larger Conversation students brought into the classroom or identified with, I also examine how these sides of the Conversation constrained or supported student learning climate change science, and how student understanding of the larger Conversation deepened over time. Certain voices in the climate change Conversation may be aligned to

particular ways of knowing and being. For example, as polling research shows, many of the voices that oppose the scientific consensus may also align with Republican values and identifications. I seek to understand how students' pathways of knowing, being and doing through the personal lens, and then tie the ways of knowing, being and doing that they leverage back to the broader societal Conversation about climate change.

## **Methods and Study Design**

### *Study Context*

This work consists of qualitative case studies of five students who participated in the second pilot study of an *Ecological Impacts of Climate Change* curriculum in the fall of 2011. The climate change curriculum is a subset of a larger curriculum development effort. The overall goal of this project is to create several year-long courses in English Language Arts, life sciences and algebra for high school freshmen. These courses aim to re-imagine what is possible in a classroom setting by incorporating cutting edge technologies, social networking, contemporary content, authentic disciplinary practices and access to world-class experts.

The life science course was created using a design-based research approach with an eye to giving students opportunities to engage in authentic scientific problems, to utilize scientific practices such as performing fieldwork, analyzing and using computer models, and writing scientific texts. The curriculum used a social media platform that connected students to each other, and also to disciplinary experts. These disciplinary experts— a mixture of ecologists, oceanographers and atmospheric scientists in the climate change

unit— reviewed student work, interacted with students via Skype, and visited the classroom.

An important design principle in this curriculum was the bridging of students out-of-school experiences and interests, leveraging students' existing knowledge, attitudes and expertise on the subject matter, and positioning youth as developing experts. To this end, this climate change module began the unit by having students surface their initial understandings of and experiences with climate change. Students then examined the portrayals of climate science in the popular media, and analyzed the arguments and evidence made by figures on both sides of the social controversy around climate change. In the rest of the unit, students conducted fieldwork related to phenological (timing of life cycle) shifts and climate change, investigated a case study of climate change impacts on a species of interest using GIS tools and climate model data, and created infographics that communicated their findings. During the unit, they received feedback from ecologists and climate scientists on their work, talked with them via Skype, and answered questions about scientific content and careers on the social networking platform.

In Fall 2011, we conducted our second pilot study of the climate change curriculum in two 9<sup>th</sup> grade classrooms at Quartz High School, an alternative school. Our study took place during the first year that Quartz High School was open, and our teacher, Eric, was a first-year teacher. Eric told us that the high school demographics were fairly similar to that of the surrounding city, which is predominantly middle-class and Caucasian (66%) or Asian (25%). In addition, the school had received many more male applicants than female, so both classrooms had more than two times as many boys than girls. These case study students are all male; while there were several girls I was interested in pursuing as case

study subjects, I was unable to conduct exit interviews with these students due to a scheduling conflict, and as a result could not adequately describe their learning trajectories. Timothy, Luke, Walt, Gareth and Samson were selected for further analysis for two reasons: 1. I felt they had scientifically interesting trajectories throughout the curriculum, with respect to their attitudes toward and understandings of climate change and 2. I had the richest data set on them due both to their classroom participation and exit interviews.

### *Data Sources*

Data was drawn from the following sources:

- Video observations of Eric's Period 1 classroom activities during the fall pilot study (~30 hours from Oct. 17- Dec. 6, 2011)
- Video-recorded exit interviews with the students at the end of the unit (between 30 –60 minutes per student). Students were interviewed in pairs or, in one case, a group of three.
- Curricular artifacts including pre- and post-tests, student work, student posts on the social media platform, responses by experts to student work, student responses on weekly engagement surveys, and digital photographs of students engaging in classroom activities.
- Qualitative, ethnographic field notes of classroom activities (~80 pages)

Field notes, and audio and video-recordings were reviewed. After outlining the storyline of each case study students' pathway through the curriculum, I then went through the data corpus a second time, identifying significant moments relevant to students'

learning, reasoning about or identification with climate change science, and these moments were transcribed for further analysis. Analysis included identification of particular ways of knowing and being that were leveraged by the students (e.g. Identifying as someone who enjoys debating, looking for and valuing multiple lines of evidence, valuing environmental stewardship), and connections of these ways of knowing and being to relevant to societal and scientific climate change Conversations (e.g. politics, sustainable energy, various lines of scientific evidence, etc.). This analysis was accomplished using an emergent, iterative strategy. After repeated reviewing of this data corpus, assertions were generated and tested as described by Erickson (1986) for both within each case study, and for emergent themes across case studies. This process included triangulating evidence from data sources and searching for confirming and disconfirming data.

## **Analysis and Findings**

### *Classroom Overview*

Students surfaced their interest in and awareness of the tensions between politics and scientific dimensions of social controversy around climate change on the first day of instruction. Students' initial attitudes toward climate change ran the gamut of the Six Americas, from Alarmed to Dismissive. Our five case study students represent this range. From the beginning of the unit, Gareth and Walt believed that climate change was happening and that it was human-influenced. Timothy and Luke were equally convinced that humans were not influencing climate change, and that if climate change *was* happening it was due to natural variability. Samson was undecided. Generally, the students were enthusiastic about the idea of debating evidence for climate change in class.

The discussions of evidence for climate change could become quite heated. Over time three students—Luke, Timothy and fellow-student Jeremy (not a case study student)--were positioned as the “deniers” in the class. The social interactions between these three students and the other students in the class, particularly Walt, as seen in the excerpt below, influenced all five of the case study students’ pathways through the unit. In this excerpt, a researcher is leading a discussion about scientific evidence for climate change. There is a graph projected on the smart board showing human emissions of CO<sub>2</sub> over time; prior to this the students have been discussing the Keeling Curve, which shows measurements of atmospheric CO<sub>2</sub> from the 1960s to the present. Prior to this excerpt, Luke challenged the researcher, saying that the graph doesn’t “prove” anthropogenic climate change because it does not show a direct connection between human emissions and warming. As the researcher, tries to help Luke make this connection between carbon dioxide emissions and global warming, other students interrupt to either dispute or support Luke’s assertion.<sup>6</sup>

1. **Researcher:** So we talk about energy consumption. What does a lot of energy produce?
2. **Luke:** CO<sub>2</sub>.
3. **Researcher:** CO<sub>2</sub>, and what did we just talk about with the Keeling Curve?

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<sup>6</sup> Note on transcription: Because this was a noisy classroom environment and speakers often interrupted each other, talked away from the mics, and talked quickly and/or quietly in small groups at their tables, pieces of the conversations were inaudible or unintelligible, and are marked accordingly.

4. **Walt:** *((turning in his chair to talk to Timothy, Luke and Jeremy))* //But we still know CO<sub>2</sub> is a greenhouse gas that causes global warming.
5. **Researcher:** This graph that's measuring--
6. **Luke:** //But we don't know greenhouse gases cause global warming, that could just be--
7. **Jeremy:** That's just a theory. We don't actually know for sure.
8. **Timothy:** We don't have millions of years to prove it.
9. **Luke:** Right.
10. **Timothy:** It takes ten thousand years for an ice age, we don't know  
*((inaudible))*
11. **Researcher:** //For the Keeling curve though, the Keeling curve is measuring the amount of CO<sub>2</sub> in our atmosphere right?
12. **Luke:** Yes.
13. **Researcher:** And what was the general trend that we saw for the CO<sub>2</sub> from the data?  
  
*((Jeremy and Timothy fist-bump))*
14. **Luke:** That it's increased.
15. **Researcher:** That it's increasing.
16. **Jeremy:** *((in a fast undertone to his table))* That's not proof of *((inaudible))* over fifty years *((inaudible))*
17. **Justin:** //Jeremy, I don't care!
18. **Gareth:** *//((said like a cheer))* Neutral!
19. **Justin:** //Yea(h)h. *((Gareth and Justin fist-bump))*

*((1 minute of continued talk about the graph until the bell rings. After the bell rings, the students start packing up to leave and continue talking.))*

20. **Jeremy:** *((in a loud voice, to catch Luke's attention))* Luke, Luke! You are a genius. Thank you for finally doing that.
21. **Timothy:** //Luke. Luke. Luke Luke. I admire you and you and that you (backed?) Jeremy up.
22. **Teacher:** //We will answer your questions tomorrow.
23. **Jeremy:** Yes, thank you for doing that, Luke. We needed someone to do that.
24. **Timothy:** Jeremy, it's 150 years and if you look--
25. **Luke:** If you look at the ice core data *((inaudible))* the temperature rise—
26. **Jeremy:** There's an 800 year gap
27. **Luke:** Right.
28. **Jeremy:** Someone needs to explain that why that's happening. Why that is.
29. **Researcher:** We will get to it, Luke.
30. **Teacher:** Luke, we'll talk about that tomorrow.
31. **Timothy:** Even though there's *((inaudible))* (not much degree difference?)
32. **Jeremy:** Luke, thank you for being Republican.

This excerpt provides a window into some of the typical social dynamics that were at play in the classroom. Jeremy, Luke and Timothy often supported each other to challenge the scientific evidence presented. In one example, presented later in this chapter, Jeremy offers further backing to support Timothy's evidence about natural variability (i.e. it

was warmer when there were dinosaurs), and Luke comments that Timothy has made an “excellent point” about natural variability. In addition in this example, Jeremy, Luke and Timothy ignore Walt’s interjection; Walt was the most vocal proponent for anthropogenic climate change, and would often argue with Timothy, Jeremy and Luke. Finally, Jeremy and Timothy both express their gratitude to Luke for challenging the researcher in class, and Jeremy connects this to Luke being a Republican. Luke’s positioning as a Republican in class, and Jeremy’s identification as a conservative Republican played a key role in the classroom dynamics, and is discussed in greater detail in Luke’s case study. These social interactions that supported the challenging of the scientific evidence were important in that they kept the dialogue about evidence for climate change present in the classroom, and created an identity for Luke, Jeremy and Timothy as opposed to anthropogenic climate change. While Timothy and Luke had both reevaluated their opinions by the end of the unit, only Timothy was vocal about it during class time; Luke only revealed his new ideas in his exit interview.

Unlike Walt, Timothy, and Luke, Gareth and Samson were rarely vocal in the classroom debates about causes of climate change. When Gareth did speak in class, it was usually to ask a clarifying question about the scientific content. As seen in the above excerpt, Gareth positioned himself as “neutral” in the debates in class. He worked at a table with Timothy, Jeremy and fellow “neutral” student Justin, a table where Timothy and Jeremy were often engaged in discussing natural variability and how that could be used as evidence against anthropogenic climate change. When Timothy and Jeremy fist-bumped each other after making a point against anthropogenic climate change in the discussion above, Gareth and Justin also fist-bump, but assert themselves to be “neutral.” Unlike Walt

who firmly aligns himself with the pro-anthropogenic climate change side, Justin and Gareth decide instead to remain outside the debate. As seen in Gareth's case study, the discussion of controversy and evidence against climate change actually made Gareth less certain of his original ideas about the causes of climate change.

Just as the students' initial positions on climate change and their participation in the class varied, so to did their learning trajectories throughout the course. Timothy, for example, had an "aha" moment that dramatically changed his mind about human influences on climate change, while Luke cautiously revised his ideas over the course of the unit, and Walt found more evidence that supported his initial understanding. Though each of these students had their own unique trajectory, the ideas of scientific evidence for and against anthropogenic climate change, and the political affiliations of the various voices in the social controversy were important themes in all five case studies. Though a negotiation between scientific evidence and socio-political controversy was present in each case, the political dimensions were more visible in Luke and Gareth's reasoning about the issue, while Walt, Samson and Timothy's trajectories were more grounded in understanding scientific evidence. Because of this, I have organized the case studies under the major themes of political and scientific ways of knowing, being and doing. I then further discuss how understanding the interactions of these two kinds of ways of knowing, being and doing, in addition to supporting the important interactions on the interpersonal level (such as family interactions or social positioning in the classroom), can help us understand these youth's attitudes toward and support their understandings of climate change science.

## **The Role of Political Ways of Knowing, Being and Doing**

The students' identifications with particular political parties, their familiarity with socio-political dimensions of the climate change Conversation, and their interest in the interactions between science and politics, were important in shaping their initial conceptions about climate change and their experiences during the ecological impacts of climate change unit. The case studies in this section demonstrate the importance of accounting for these political family contexts that influence conceptual change in climate science.

In the first analysis, I examine Luke's navigation between a family context that is hostile to the science presented in class, and explore his encounter with a new epistemological and conceptual frame that challenged his own personal epistemology. In the second case, acceptance of climate change aligned with Gareth's personal and family epistemologies; however, through interacting with Luke and other students who challenged the scientific evidence, Gareth began developing a more sophisticated evidentiary epistemology of climate science that resulted in him questioning his initial conceptions. I first describe Luke and Gareth's pathways, and then synthesize them in a discussion of the instructional needs and aim that are implicated by these political and familial contexts and the relation to the teaching and learning of other socially controversial science. These case studies demonstrate the important of supporting students as they navigate multiple social contexts for science learning, and the need to provide space for youth to surface their preferred political ways of knowing, being and doing in order to explore how to integrate, reconcile and revise these with scientific evidence.

### *1. Luke*

Luke had a deep interest in politics and the interactions of politics and science, and began the unit believing that humans were not influencing current climate changes. Throughout the course, Luke realized that there was more evidence for human-influenced climate change than he initially thought, and revised his understanding of the causes of climate change. The most striking characteristic of Luke's experience with the climate change curriculum, however, is how Luke's political affiliations, his deep interest in and understanding of politics and his mistrust of the mingling of politics and science informed his own belief system about climate change, his social positioning in the classroom, and his personal learning habits.

In his exit interview, Luke talked about the relationship between his initial ideas about climate change and his father's political views. Luke characterized his father as "very, very far right conservative" and "really into the politics [of climate change]". Luke says his father's ideas about climate change would be "all the Rush Limbaugh show," i.e. his father's opinions would be directly informed by conservative pundit Rush Limbaugh's opinions as discussed on Rush Limbaugh's show. Rush Limbaugh is an influence on Luke's family life to such an extent that Luke identified himself as a "Rush baby," which he explained as: "Your parents listen to Rush and you grew up listening to Rush." This predominant influence on his family life likely profoundly impacts Luke's extended learning pathway. As Luke describes in the excerpt below, his father liked to get involve in Luke's school activities, and espoused conservative views of these issues:

1. **Researcher:** So then, so have you talked to your family about this a lot? Cuz you mentioned your dad watches Limbaugh all the time.
2. **Luke:** //Yeah, my, my dad's, um, funny about this, but yeah I talk to him about it. We've-- he likes to get involved in what we're learning, what I'm learning about in school and tell me his opinion about it. We-- we're doing the Occupy Wall Street thing in [the English teacher]'s class so we've been talking about that a lot recently. But when we were talking about global warming he was, you know, making me listen to the Rush Limbaugh stuff sometimes on it, and he was just like *((shakes hand, in a deep voice))* "Braah, liberals, braah!"
3. **Researcher:** So does he just chalk it up to people being liberals and then not listen? Or does he--?
4. **Luke:** No, he listens, um, I just think that he's just kind of stuck in his ways and only believes Rush. So. *((laughs))*

Not only is Luke's family conservative (Luke's mother also leans Republican and conservative, but is less political, according to Luke), but Luke's father also takes an active interest in what his son is learning, and is vocal about "his opinion about it." This is true not only for the climate change unit, but also for other units that have political undertones, such as the unit in their English class on the Occupy Wall Street Movement. During the climate unit, Luke's father found an article on hacked emails from climate scientists, which Luke describes as showing that "they were saying they made a new model that was

showing global cooling for the next 75 years and they were like: 'Oh, we gotta hide this' in their emails. Supposedly. I never read the article." Luke's father referenced this article to Luke, who brought it up in class, but unfortunately we were never able to locate it.

Luke jokes about his father's approach to the topic, mimicking him and characterizing his father as "funny about this." Though Luke was influenced by and valued his father's (and Rush Limbaugh's) input, Luke ultimately distanced himself from his father's position, and the fact that his father is "stuck in his ways and only believes Rush." Luke distinguishes his own ways of knowing and being from his father. Luke describes his father's way of knowing as dependent on a single information source, whereas Luke's own way of knowing privileges seeing multiple sides of an issue. He told us that unlike his father, "I can actually filter out what he's [Rush's] saying. My dad can't." And unlike his father, Luke identifies himself as an Independent that leans right: "I'm mostly Independent. I think I am a little biased toward the right, mostly because I'm a Rush baby." Despite his own personal identifications, in the class Luke was often positioned as and identified by others as a Republican, a positioning he seemed to accept and at times encourage.

At the beginning of the unit, Luke's understanding of climate change was informed by this exposure to the conservative side of the Conversation around climate change. He told us in his exit interview that though prior to the unit he was aware of human emissions of CO<sub>2</sub>, he originally ascribed any possible changes in climate to natural variability, an outlook that was influenced by his family.

**1. Luke:** So, I mean I had a lot of influence [from his family]. I knew that the humans were putting CO<sub>2</sub> into the air and I knew that probably wasn't the best thing

to be doing and I knew that the temperature was increasing faster than it has been, but I was still kind of in the mindset that it's just earth going through its phases and it'll all be fine in a thousand years or whatever. Uh, or maybe it's just time for another big cy-- change-- change in the earth's atmospheric cycle and it's just going to happen. *((small shrug))* You know, we'll go live on Jupiter or whatever.

In this quote, Luke explains that his initial attitudes were influenced by his family's beliefs. He thought climate change was due to natural variability, that is the "earth...going through its phases" and that this was not an issue to be worried about. This definition of natural variability as the "earth...going through its phases" is also the one Luke first used in the classroom. On the first day of the unit, the teacher asked the students what they had heard about climate change. Luke answered with two possible mechanisms for climate change—one that he attributed to Democrats and one to Republicans.

1. **Luke:** It's uh, there's two opinions on it. One's like the Democrat's side and the others the Republican side.
2. **Teacher:** Funny how that seems to follow party lines, isn't it?
3. **Luke:** Yeah.
4. **Teacher:** Hmm...anyway. Please continue. *((Laughter))*
5. **Luke:** It's uh, the Republican side says it's the earth going through its phases. Uh, yeah *((laughter from students as the teacher writes on the board))*.
6. **Teacher:** Sorry.

7. **Luke:** The Democrat's side is that humans are evil and we're destroying our earth.

In this excerpt, Luke presents two “opinions,” or voices in the Conversation about climate change— one that he ascribes to the Democrats (that “humans are evil and we’re destroying our earth”) and the other to the Republicans (that “the earth is going through its phases”). Shortly after this exchange, Luke states that he believes that climate change is due to “the earth going through its phases,” using the same wording that he associated with the Republican understanding of climate change, and that he used in his exit interview. Thus, Luke initially aligned his own initial belief system with the Republican “side.”

Given the prevalence of this positioning of Luke as a Republican, I was surprised to discover his personal political identification as Independent in the exit interview. In the classroom, this political positioning as a Republican had important social learning consequences for Timothy, Jeremy and Luke. For example, Jeremy often positioned himself and Luke as on the same side of the classroom debates because they were both Republicans. As we saw in the earlier excerpt of classroom social interactions, after discussing evidence for climate change, Jeremy thanked Luke for being a Republican (and, presumably, for standing up for Republican viewpoints) as the students left the class.

In his post-test, Luke indicated that his understandings of the mechanisms of climate change had in fact changed during the unit. He wrote that he “thought the people talking about climate hchange[sic] where[sic] all hippys[sic] with no facts to back up there[sic] arguments, now i[sic] relise[sic] they have facts.” This statement reinforces the idea that Luke’s original conceptions of climate change were tied to perceptions of the

ideological aspects of the climate change Conversation, but shows that there has been a significant shift in Luke's epistemological stance. Luke, who does not identify as Democratic, liberal or hippie, similarly did not identify with anthropogenic climate change. However, as he learned more about it, he realized that there was a deep scientific way of knowing associated with the climate change Conversation in addition to the socio-political aspects, and that there was, in fact, more evidence than he originally thought. For Luke, his pathway involved moving from primarily seeing climate change as affiliated with socio-political ways of being (being a Hippie or a Rush Baby) to viewing it as affiliated with scientific ways of being and knowing. However, Luke had to negotiate the fact that these scientific ways of being and knowing conflicted directly with his political affiliations, the perspectives of his family, and his social reputation in school.

In his exit interview, Luke told a researcher that he did think that there was a human influence on climate. In the following excerpt, the researcher begins by following up on a comment Luke made about how people should drive hybrids, to find out if that indicates that he does think there is a human influence on climate change.

1. **Researcher:** So you do think that there is a human influence.
2. **Luke:** Yes, there is a human influence on it, but I think that it's reversible and it's not going to be Armageddon, we're not going to have to go have to live on Mars or whatever.
3. **Researcher:** Yeah. So you don't think it's just a natural variation.

4. **Luke:** No, it's not just natural variation. Um, and there-- and again there's been other models out there that are saying it's not going to be a big deal and it's going to reverse pretty soon.

In line 2, Luke replies that he does in fact think that. This was not the answer the researcher was expecting, and so she reiterates that he does not think changes in climate are due to natural variation. Up to this point Luke had not given any indication in class that he thought that climate change had a significant human influence. It is possible that this was a strategic social positioning move on Luke's part that allowed him to maintain his existing position as a contrarian in the class, despite his shifting perspectives. Luke's reluctance to surface his changing conceptual understandings in the classroom has implications for instruction, as it points to the importance of giving students moments outside of a potentially politically-charged classroom space to engage with and report their ideas. That is, what is visible in the whole group dynamic doesn't necessarily represent the students' individual understandings.

Luke reiterates that he does think there is a human influence, but goes on to say that it's "not going to be Armageddon" and it might "reverse pretty soon." Luke's language of "Armageddon" connects back to his original speech about the "opinions" about climate change, with the Democrats thinking that "humans are evil and we're destroying our earth." In addition, Luke repeatedly references going to live somewhere else (either a country or another planet) flippantly as a solution to climate change impacts. He does not view the possible impacts of climate change as serious or adversely affecting him— in fact, this

excerpt from his exit interview indicates that he thinks that climate change may likely reverse, a piece of evidence he heard from his father.

Luke's understanding of and opinions about climate change shifted throughout the unit and will likely continue to shift in the future as he encounters new evidence. At the end of the class, Luke still felt that the issue was very politicized, and that the politicization affected the science that was being done. In his post-test and exit interview, Luke expressed a desire for the science and politics to be separated from each other. In the post-test, Luke stated that he did think that climate change was happening, but when asked what caused it, he answered "other" and explained that there were still a lot of theories in play about the causal mechanisms:

Other: theres[sic] to[sic] many thereys[sic] going around right now, we need to just let the scientists actually do work, and figure out whats[sic] actually happining[sic] without all the politics that are involved.

From Luke's perspective, the politics are too heavily involved with the science, and this has led to a confused proliferation of theories about the causes of climate change. This is an interesting perspective, because in the scientific community, anthropogenic climate change is a consensus view, and this knowledge is seen as standing outside the social, political controversy. At one point, Luke asked one of our climate science experts about whether or not she thought the science was influenced by politics, and the scientist said she did not. Luke disagreed with this point, and explained it to us in the exit interview saying:

"Someone had asked her do you feel like politics are involved in science and she just flat out

said no. Um, and I really disagree with that. I think there are a lot of politics in science.” Part of this disagreement may have been a subtle distinction that could be made between the political influence on the reported results of scientific work, versus the ways that particular scientific questions are chosen for investigation. Likely, the scientist was trying to make the point that ideally a scientific way of knowing or being achieves political neutrality in that the results of research is held to a standard of objectivity. For Luke this was frustrating, however, because he had a post-positivist stance on science that recognized the role politics played in the funding and overall direction of scientific work.

After this discussion, Luke made a comment on his weekly survey that he would like to hear from a Republican climate scientist, but couldn't because they “don't seem to exist.” This comment reveals an assumption that Luke was working with— namely that none of the climate scientists he had been interacting with were Republicans, an assumption he held even though none of the scientists had revealed their political affiliation. This statement from Luke indicates that hearing from a Republican scientist would have potentially been a powerful experience for him, because it could have provided him with an opportunity to engage with someone about the scientific claims about climate change who also had experience negotiating the politicization of the issue from a conservative standpoint.

Luke believed that the government should not be funding scientific work at all, because that might cause bias in the results, and because the government had other responsibilities (like fixing the current economic crisis). Luke explained that even if scientists are trying to be objective, at a subconscious level they may be biasing their results toward what their funders want to hear, a view that indicates Luke has a post-

modern understanding of science. Instead, in his exit interview, Luke asserted that science should be privately funded. If the government stopped using tax money for science, citizens could take the money they would otherwise have paid for taxes to fund scientific work. As he discussed this further, Luke admitted that this might not solve the problem of bias, but he thought it would be better than the current system.

1. **Researcher:** So who would you trust, then, to fund scientists if you don't trust the government? Or would there be anyone? Maybe there's no one, but.
2. **Luke:** Well, scientists I don't think like to lie. But I do think that they can change evidence a little bit, tweak it a little bit, with outliers and that kind of stuff to make it more agreeable. But I think that if someone, if a scientist is funded by a nonprofit organization, Bill and Melinda Gates Foundation, something like that, then that would be reliable.
3. **Researcher:** So you don't think then nonprofits or other, um, nonprofits have an agenda then?
4. **Luke:** Well some of them do. I mean, it depends on the nonprofit. But someone being funded by, uh, see I'm trying to think of one, but, a political support group that's nonprofit. That would be potentially biased as well.
5. **Researcher:** So is there any way to get rid of bias?
6. **Luke:** Not really.

Luke initially posits that scientists don't "like to lie" but may be slightly tweaking their data "to make it more agreeable." It is unclear whether Luke is taking issue with scientific practices of processing data (e.g. smoothing data, performing statistical tests to remove outliers) that are accepted scientific practices, or if he is talking about "tweaking" that violates standard scientific ethics. Likely, Luke does not have an understanding of the difference between these two practices, and why one is acceptable to the scientific community and the other is not. He then states he thinks that scientists funded by nonprofit organizations might potentially be less prone to bias than those of the government, but when the researcher brings up that they might also have an agenda, Luke admits that nonprofit results might be "potentially biased as well," and that there might not be a way to remove the bias.

1. **Researcher:** So is there any way, do you think there's anything in place that will help-- that can help, um at least limit bias?
2. **Luke:** Yeah, I think that there are people out there who have gotten good at being able to see both sides of the issue and approach things, uh, without bias but I think that with the science thing there are always a lot of people working on it and there's probably going to be one guy who isn't able to do that and see things from both sides of the issue. So there's potential for there to be something in the data that isn't 100 percent accurate.

In the above excerpt, Luke raises the valid concern that even if most people are doing good science “without bias,” there could potentially still be the occasional person who introduces inaccurate results or data into the mix. He identifies “being able to see both sides of the issue” as a way to help limit bias in the work. This resonates with his earlier discussion of how his own ways of knowing contrasted with those of his father. He stated earlier that unlike his father who listened only to Rush, he himself was able to see things from multiple perspectives. Scientists, according to Luke, should adopt a similar way of knowing. Ideally, through scientific knowledge construction processes problematic data or results from this rogue “one guy” should be identified over time, and scientific understandings revised. It is unclear if Luke does not have enough experience with the scientific community to understand these scientific processes, or if he does know this, but believes that the way the community works is still problematic.

Because Luke still sees climate science as intertwined with politics, he sees it as lacking the impartiality that he values. It is possible that a greater understanding of scientific processes or examples of conservative Independent or Republican climate scientists could address Luke’s reservations about the bias within climate science. However, it is also possible that given the strong socio-political themes in the Conversation of climate change and Luke’s political identifications, he may continue to be cautious about climate science research.

## *2. Gareth*

Gareth had strong political associations with climate change tied to his family’s Democratic beliefs. These associations determined his initial beliefs about climate change.

As the class progressed and he became aware of socio-political dimensions of the climate change Conversation beyond that of his family's beliefs, his own perceptions began to shift. Gareth surfaced his initial political associations in the very first interchange of the unit during an introductory discussion of the students' existing knowledge about climate change.

1. **Teacher:** But my question for you all, first of all, is what is climate change, what do you know about it? What is it?
2. **Gareth:** *((quickly))* Democrats. *((laughter from students))*
3. **Teacher:** Climate change is the Democrats *((more laughter))*. *((The teacher picks up marker to write on the board))* Gareth, explain more to me. What do you mean (by that)?
4. **Male Student:** Oh, here we go.
5. **Gareth:** Oh gosh.
6. **Teacher:** Why are the Democrats climate change?
7. **Samson:** Because.
8. **Male student:** Because they're driving Priuses.

The teacher begins the unit by asking a question to surface students' initial understandings of climate change, and Gareth immediately responds with "Democrats," bringing politics into the unit even before any science has been mentioned. Though the teacher asks Gareth to further explain his remark, Gareth doesn't at this point because other students jump in, asserting that Democrats are climate change "because they're driving Priuses." These

responses indicate that the students' initial conceptions of climate change were tied to the socio-political dimensions of the climate change Conversation. In particular, climate change is associated with the kinds of people who are Democrats and drive Toyota Priuses, a fuel-efficient hybrid car. This Democratic dimension of the Conversation is then associated with a Prius-driving, Democratic way of being.

Gareth identifies his own family as participating in this “Prius-driving Democrats” way of being, with the slight distinction that his parents drive a zero-emission Nissan Leaf instead of a Prius. He mentions the fact that his family owns a Nissan Leaf several times throughout the unit, and connects his family, if not directly himself, with concerns for energy efficiency and the environment. For example, during one class period, I had a long conversation with Timothy about evidence for climate change, during which Timothy re-evaluated his initial skeptical beliefs. Gareth— who had been at the same table working on his own project during the discussion— commented to me as he was leaving the room: “You don't have to convince me. My parents are Democrats, and my mom has a Leaf.” In this statement, he asserts his own conviction that climate change is happening (I don't “have to convince him”) and supports this by indicating that his family are the *type of people* that don't need convincing— that is Democratic, Leaf-driving people.

In his exit interview with Walt and fellow-student Chris, Gareth directly connects his family's way of being to his initial understandings of climate change. He again uses the Nissan Leaf as an example, and this time connects his family's beliefs and actions to his own initial conceptions of climate change.

1. **Gareth:** So they, they're really energy sufficient, you know they, they uh--

2. **Researcher:** Your family.
3. **Gareth:** They, uh, they you know, they actually have-- the reason they bought a Nissan Leaf *((Walt laughs))* so that
4. **Chris:** //Those things are silent.
5. **Gareth:** And they, like, strong belief that humans are one of the main causes of climate change which currently, and uh, they want to kind of reduce as much of their, uh, global, like, carbon—
6. **Walt:** Footprint.
7. **Gareth:** Footprint. That's what it is. As much as possible.
8. **Researcher:** So do you have the same values and beliefs or...?
9. **Gareth:** Um, sort of, like, that's all I grew up with. I didn't really grow up with anyone else like, saying, that doesn't happen, that isn't happening. So yeah, I kind of thought that at the beginning of the unit but I didn't really have, like Walt said-- I don't really, I didn't really have any empirical evidence, you know, anything backing up what I thought, so yeah.

Gareth explains that his family bought the Nissan Leaf to reduce their global carbon footprint, and that they strongly believe that humans are “one of the main causes of climate change.” Because he had not been exposed to other ideas, i.e. this idea was “all I grew up with” he agreed with his family at the beginning of the unit but didn’t have an understanding of the scientific evidence that supported the idea. In the classroom, Gareth

had the opportunity to engage with people who did say “that [human influenced climate change] doesn’t happen,” and that experience shaped his own ideas about climate change.

Having these other, new, influences around that were critical of anthropogenic climate change influenced how Gareth viewed the issue. In fact, Gareth may have become *less* sure of the magnitude of human influences on climate change throughout the course of the unit. In his post-test and exit interview, Gareth gave two different accounts of his pathway through the course. In his post-test, Gareth indicated that he thought climate change was caused mostly by human activities, and, when asked if his views had changed, responded that he had gained more evidence to support his beliefs:

I've learned a lot of new things about global climate change and have found a lot of more empirical evidence supporting climate change so know[sic] I am more sure of climate change than I was before.

From the post-test, it would appear that Gareth is more certain of his initial belief that climate change is happening and is human-influenced. In his exit interview, however, he tells a slightly different story. In his exit interview, Gareth discusses how he transitioned from assuming humans were causing climate change to being more aware of the social controversy, specifically around anthropogenesis. Gareth explained that though he understands the scientific consensus is that anthropogenic climate change is happening, and that this is also the dominant understanding across the world, he wanted to see more evidence before he fully makes up his own mind. Gareth told us that he wished the unit had shown more science from “both sides” of the debate, so that he could better evaluate the

evidence for himself. He sees the evaluation of both sides as an important part of his learning process, even though he recognizes that the scientific consensus is that climate change is influenced by humans.

It is difficult to reconcile the two somewhat contradictory statements that Gareth makes. It is possible that the post-test statement should be read as that Gareth is only “more sure” that climate change itself is happening, not that it is human caused. Alternatively, it is also possible he said that it was human caused because the post-test felt like a testing situation in which a “right answer” was expected, and human influences would be the “right answer.” However, even though he states in the exit interview that he’s not sure of the cause, it seems likely given the post-test answer and his behavior in class, that he is leaning toward the idea that current climate change is mostly influenced by humans. Finally, it is possible that he changed his mind between the post-test and the exit interview.

Whether Gareth ultimately ended up more or less sure of the mechanisms of climate change, his statements demonstrate that his understanding of climate change is a dynamic one, influenced both by the science he learns as well as by the socio-political controversy that he was exposed to through social interactions in the classroom. Gareth has begun a process of questioning a previously unquestioned belief using scientific evidence; this is a productive move from a long-term perspective of Gareth’s developing scientific literacy. Prior to the unit, he thought humans were influencing climate change but hadn’t deeply engaged with the topic, and this belief was not grounded in scientific evidence. The unit deepened his understanding of both the scientific evidence and the political dimensions. As

a result, he wanted to continue deepening his understanding by learning more about the scientific evidence and the social controversy.

### *Discussion of Political Influences*

Research on the cultural foundations of learning conceptualizes student learning as culturally mediated. Learners' experiences within a particular environment are shaped by the ways of knowing, being and doing they bring to that environment, and by the ways of knowing, being and doing supported in that environment. Calabrese Barton (1998) argues for scientific instruction that removes barriers between science and student's personal, lived experiences such that learners can make "connections between students' life worlds and science to be made more easily...[and] providing space for multiple voices to be heard and explored" (p. 389). This perspective implies that in the design of instructional experiences, designers should attend to supporting student voice and connecting to learners' existent ways of knowing, being and doing. For the students in this class, the relevant cultural experiences had a strong political dimension. It was of paramount importance that students were able to surface these identifications and values so that they could engage with the science. Luke, for example, was able to explore the tensions between his initial belief system and the scientific knowledge. He then began to develop a more nuanced understanding of the societal Conversation around climate change as he deepened his understanding of the scientific evidence.

Luke faced challenges in navigating multiple social contexts that privileged different views of climate science. While Luke progressed in his conceptual understanding of the scientific evidence for climate change, and in his epistemological understanding of the

workings of the climate science community, this work was challenging and at times frustrating for him. Bell and Linn (2002) highlight that, from a knowledge integration perspective, accomplishing the kind of conceptual change work that Luke did is difficult: “While successful science learners link and connect their ideas, selectively explore and incorporate competing perspectives, and build a more coherent and robust understanding, most students find this process of knowledge integration challenging” (p. 325). It is important to consider the potential challenges for students integrate knowledge across these multiple contexts, a point discussed further in Timothy’s case study in the next section.

A comparison is often drawn between the learning of climate change, and that of evolution, another science topic that has a controversial social context. In the past fifteen years, researchers interested in student perceptions and learning of the theory of evolution have described how students’ understandings are related to other social, religious and epistemological beliefs (e.g. Hokayem and Boujaoude, 2008; Smith, 2010a, 2010b; Winslow, Staver and Scharmann, 2011; Sinatra, Southerland, McConaughy and Demastes, 2003). In a review of literature on the teaching and learning of evolution, Smith (2010a, 2010b) examines the philosophical and epistemological issues associated with teaching and learning evolution. He discusses the need to better understand the distinctions between *knowing*, *understanding*, *accepting* and *believing* the theory of evolution, and the correlations and causal relationships between these four. Learners may struggle with conceptualizing scientific knowledge, may have incorrect assumptions about scientific processes or scientists (e.g. that all scientists are atheists), or may equate different kinds of evidence (e.g. religious texts and scientific data). Smith concludes that it is necessary to

attend to these philosophical and epistemological components in supporting the teaching and learning of evolution.

The data presented in this study demonstrate that attending to philosophical and epistemological issues is likely equally important in the teaching and learning of climate change science, and that it is useful to make similar distinctions between *knowing*, *understanding*, *accepting* and *believing*. Gareth, for example, initially *accepted* climate change but didn't *understand* it. As he developed a deeper understanding of the science, he was also becoming more aware of the controversy, and became less comfortable accepting the science without becoming more proficient in it.

There is, however a key distinction between the challenges faced in the teaching and learning of evolution and those in climate change science because of the different philosophical and epistemological dimensions that are at play. For evolution, the controversy primarily concerns tensions between religious understandings of Creationism and scientific understandings of evolution. This tension between religious and scientific ways of knowing leads to epistemological problems with the treatment of religious and scientific evidence; that is comparing an inductive epistemology with a faith-based one. In the social context for climate change learning, however, religion is less likely to be the dominant influence. Indeed, religious organizations have generally been supportive of climate science, and climate change behaviors ("Common Belief: Australia's Faith Communities on Climate Change," 2006; Hulme, 2009 and references therein). Instead, as seen in this study, political issues are more likely to dominate. However, in the design of learning environments for both areas it is important to attend to the tensions that may

arise for learners as they struggle to resolve tensions between the science presented and their own values, understandings and belief systems.

By highlighting political dimensions of the climate Conversation, I don't mean to imply that there could be other social influences that could potentially be at play. For example, at one point Timothy did comment that he saw climate science as potentially at odds with his belief in the Bible. However, while religion influenced Timothy, it was not the driving influence for any of our students in the manner that political affiliation was. It is possible, though, that in other classrooms other dimensions may take the foreground.

Luke would have benefited from further supports to help him negotiate these political and scientific dimensions. For example, connecting him to a climate scientist who explicitly identified with his own conservative belief system would likely have helped him continue to explore the relationships between the scientific evidence and the politics. In addition, further supporting the epistemological issues associated with climate science could also have been beneficial to his understanding of the distinctions between the scientific evidence and the politics, an issue further explored in the following section.

### **The Role of Scientific Ways of Knowing, Being and Doing**

The scientific argument for anthropogenic climate change is built on a large body of evidence that comes from multiple kinds of data sources. Understanding the cohesion of that body of evidence requires make several connections across lines of evidence, including not only conceptual understandings, such as the role this carbon dioxide plays in the environment, but also understanding of the scientific processes by which scientists' construct their understandings and obtain their data. Previous research has demonstrated

the difficulty students have in conceptualizing the greenhouse effect (e.g. Shepardson et al., 2010) and explored learning progressions for climate change (e.g. Jin and Anderson, 2010).

Knowledge in pieces and knowledge integration views of conceptual change suggest that scientific instruction should support students as they “integrate, connect, sort out, and combine their repertoire of ideas” and link new ideas into their existing repertoire (Bell & Linn, 2002, p. 322). Roseman, Linn & Koppal (2008) describe knowledge integration as “a lifelong process that involves continuously seeking additional, more valid and more concise connections among scientific ideas” (p. 13). In order to better support students changing conceptual understandings of climate change, it is important to evaluate what knowledge students bring to the classroom, what Slotta & Linn (2009) describe as the “repertoire of rich, confusing, and intriguing ideas” that students have. In addition, we need to identify what conceptual ideas students readily grasp, and which conceptual ideas are more challenging.

The three case studies in this section highlight some of the important conceptual and epistemological dimensions of climate change science learning. These epistemological and conceptual dimensions for climate change science learning are discussed in greater detail in Chapter 1 of this dissertation. In addition to identifying students’ initial ideas and beliefs related to climate change, Timothy’s case study also highlights challenges that face students as they make connections across multiple studies and lines of evidence. A sophisticated understanding of climate change science requires making connections across lines of evidence that support a multiple-step scientific argument for climate change. That

is, in order for humans to be responsible for current climate changes, the following must be correct:

1. Carbon dioxide is currently increasing in the atmosphere
2. Humans are responsible for the increase in atmospheric carbon dioxide,
3. Increased atmospheric carbon dioxide causes global temperatures to increase.

Because this is a multi-step argument, there is no single piece of evidence that connects all three of these, and that proved problematic for both Luke and Timothy, who wanted to see a single graph that showed a “direct connection” between humans and warming. In this section, I describe how Timothy, Walt and Samson engaged with multiple lines of evidence for climate change, and follow this with a discussion of the implications of these case studies for the design of instructional environments and resources, and the inclusion of disciplinary experts in climate science education.

### *1. Timothy*

Timothy began the unit convinced that humans were not responsible for climate change, but by the end of the seven-week period, Timothy was equally convinced that humans *were* responsible for climate change. What follows is an account of Timothy’s path through the climate change unit, that endeavors to capture the various lines of scientific reasoning Timothy used to support his arguments for and against climate change, as well as the other factors— such as family beliefs and social interactions in the classroom— that influenced his engagement with the scientific evidence.

### *Debating the Evidence*

At several points during the unit, Timothy discussed with the researchers and his teacher that he was the kind of person that likes being challenged. For Timothy, debating, challenging and potentially revising ideas was a way of being he identified strongly with. The fact that Timothy viewed challenging existing beliefs as a positive thing likely played a part in the fact that he ultimately changed his mind about anthropogenic climate change.

Not only did Timothy enjoy debating in class, he also brought the climate change debates back home with him. Timothy's original view that climate change was not human-influenced can be connected to his family's beliefs— specifically, Timothy told us that his father did not believe in climate change. As the unit progressed, however, and Timothy began challenging his initial beliefs he also reported that he began debating with his father at home. Timothy described his interactions with his dad in his exit interview:

1. **Timothy:** I talked about it with my family a lot, just like contradicting my dad.

Cuz my dad had so many questions, he actually educated me a lot about it, too. And it was kind of interesting because I got to learn some more.

2. **Elly:** //So--

3. **Timothy:** And my dad had some of the same ideas about he-- I could contradict him, what he actually believed, though.

4. **Elly:** So he had the same ideas as who?

5. **Timothy:** Me. He usually-- he *had* some of the same ideas, same concepts as me, but he had some different ideas than me on what was happening, so I kind of like used my evidence against him.

6. **Elly:** So what did he-- what kind of evidence did he have?

7. **Timothy:** He had like everything, everything, like everything natural causes could do, like earthquakes, volcanoes, everything and I contradicted every single one of those, except for like one where the-- I forgot what it was but it was one thing that I couldn't, I couldn't come back at. But um, I, I kind of talked to him a lot about it, and it was kind of cool, cuz I, like I can use this new knowledge and talk about it with my family and see what they think and maybe change their minds cuz it was kind of cool to me.

Here, Timothy tells me that throughout the unit he talked about climate change with his dad. Timothy's dad "educated" Timothy about the issue and helped him "learn more"; he asked Timothy questions, and debated the issue with him. Timothy stresses in line 5 that his dad "*had* some of the same ideas" as Timothy, but that Timothy has now changed his mind. Timothy's dad evidently had lots of evidence about natural variation causing climate change, but Timothy reports that he "contradicted every single one of those" except for one that he doesn't remember. Timothy speaks of arguing with his dad as a positive thing, saying that it was "kind of cool" to be able to use his new knowledge to argue with his family. Timothy's way of being of debating and challenging oneself is supported by his family life and, in this instance, was also used by Timothy in the unit to expand his understanding of climate change. Like Luke, Timothy's participation in climate change science occurred across the settings of his life. Timothy's story illustrates how students not only engage with science content at school, but also engage with the scientific topic at home. According to a "cultural learning pathway" model, these experiences navigating

multiple social contexts have the potential to influence students' learning trajectories (Bell, et al., 2006). Using this model to help frame students' navigation of the multiple discourses across place in relation to knowledge and identities is important for supporting the many students for whom climate change science learning according both in and out of the classroom, as it did for Timothy and Luke.

### *Understanding Scientific Evidence for Anthropogenic Climate Change*

Throughout the unit, Timothy, Jeremy and Luke provided several pieces of evidence to support their argument that climate change was not human-influenced, some of which directly contradicted one or more of the above claims. However, many of their argument focused on developing an alternative argument, that instead of carbon dioxide causing climate change, natural variability played the dominant role.

After the first week or so of class, Timothy and Jeremy in particular focused their inquiry into natural variability and its role in climate change. On Nov. 7<sup>th</sup>, we began discussing in detail some of the evidence of climate change, in preparation for a discussion of natural variability on Nov. 8<sup>th</sup> and a discussion of greenhouse gases on Nov. 9<sup>th</sup>. During this week, Timothy developed a theory that current climate changes and increases in population and industry could be a coincidence. On Nov. 7<sup>th</sup>, a researcher led a discussion about the Keeling Curve, historical temperature records, and ice core data, which surfaced student questions about how scientists "know" about past climate, given that we have limited historical records.

1. **Researcher:** *((to Timothy))* What were you going to say?
2. **Timothy:** Well, I mean that's only 150 years, I mean, again, again-- 10,000 years ago there was an ice age.
3. **Researcher:** //Uh-huh, that's a really good point. Yup
4. **Timothy:** Before that there was warming and more ice ages. And I mean, it could just be a coincidence that when people on earth, people increases population during, peoples' population was a big coincidence.
5. **Jeremy:** //Yeah. When there were dinosaurs, it was a lot warmer than it is now.
6. **Timothy:** Cuz, I mean, How do we know, that only in 50 years-- with only 50 years of data, and the earth has been around for billions, how do we know that fifty years--
7. **Walt:** Because we have millions in ice core data.
8. **Researcher:** So that's an excellent point. That's an excellent point that he's making about how do we know because that data is only taken for the last fifty years
9. **Timothy:** And temperature went way up and also went way down and way up without any CO2 changes.
10. **Luke:** //And also-- that's an excellent point.

11. **Researcher:** So how do we know that it's not natural variation?

This is the first time that Timothy raises this idea of coincidence in a class discussion. Timothy is thinking not only about the evidence in front of him, but also how scientific evidence in general is obtained (“how do we know”). Timothy begins by pointing out that the historical record we were looking at only provided data for the past 150 years, and if one were to go back further there would be “warming and more ice ages.” Thus he is beginning to articulate the point that 150 years is not necessarily a representative time period from which one could draw valid conclusions about future climate. In his next turn, he introduces an alternative hypothesis— that the population growth and changing climate are unrelated. He then repeats his original point saying that the earth has been around billions of years, but nuances this slightly by asking: “How do we know?” This idea of how “we know” or don’t know things is a reoccurring theme for Timothy. He repeatedly raises the idea that “we don’t know” while arguing against climate change, and at the end of the unit uses the idea that “we don’t know” whether climate impacts will be good or bad as a reason for not taking action related to climate change.

In line 7, Walt responds to Timothy’s claim that “we don’t know” by referencing the “millions [of years] in ice core data.” While Walt has conflated the ice core record (which is thousands of years long) with geological records (millions of years long), his point is valid— that there are other ways of knowing beyond direct historical observation. Timothy ignores this interjection, however, and reiterates his initial point that there is a lot of natural variability in the climate system where the “temperature went way up and way down” without correlating changes in CO<sub>2</sub>. It is unclear which atmospheric changes

Timothy is referencing at this point, but this idea of natural variability becomes the key piece of climate evidence that Timothy needs before he can construct a convincing (to him) argument for anthropogenic climate change.

The researcher positions Timothy's questions as valid, saying that he brought up a "good point." She also reframes the debate between Timothy, Luke, Walt and Jeremy as something "we're thinking about," validating both sides without condoning or directly contradicting either. This supported the practice Timothy valued of challenging and debating evidence, and opened up space for Timothy to continue to work through his ideas in class without disengaging from the topic.

The idea of coincidence and natural variability remained important to Timothy, and he continued to explore it further. On Nov. 8<sup>th</sup>, oceanography graduate student Madeleine visited the classroom to facilitate an activity on ice cores and ice ages. After class, the teacher allowed some of the students to remain behind to discuss natural variability with Madeleine. Timothy began his discussion with Madeleine by suggesting that there are large solar cycles that occur on million year timescales and are affecting climate. This initiated a discussion of changes in earth's orbital parameters called Milankovitch cycles, and how these are thought to cause the earth's climate to vary on timescales of 100,000 years. In the following exchange, Timothy interrupts Madeleine's explanation of Milankovitch cycles to present his million-year theory:

1. **Timothy:** But one thing that happened every millions of millions of years that we don't know about.

2. **Teacher:** Chances are that it wouldn't happen over the timescale of forty or fifty years like what we're seeing in the changes now.

3. **Timothy:** But that's *likely*.

The above excerpt demonstrates that Timothy is reasoning through possible alternative explanations for climate change. In line 1, Timothy states that in addition to the Milankovitch cycles that cause changes on 100,000-yr time scales that we *do* know about, there could be a similar cycle “that happened every millions of millions of years that we don’t know about.” The teacher responds to Timothy by indicating that the probability of such a cycle happening over such a short timescale is low. Timothy, however, is unconvinced. This ties back to his earlier argument that climate change could be a coincidence, and that “we don’t know.” In this exchange, Timothy is demonstrating an ability to ask critical, scientific questions and point out flaws in arguments (i.e. just because something is “likely” doesn’t make it the correct explanation). However, in this exchange he is not evaluating the validity of a theory based off of the accumulated evidence. Unlike Madeleine and the teacher, who support anthropogenic warming over the idea of an improbable undiscovered million-year cycle, Timothy affords each theory equal weight.

The next day in class, Timothy reiterates his ideas, and receives a similar response from the teacher. When Timothy brings up the timescales of the Milankovitch cycles, and his theory about a bigger cycle, the teacher confirms that this theory is a possible explanation, but then lists some of the counter-evidence, namely that scientists haven’t found a bigger cycle, and that we know where the CO<sub>2</sub> in the atmosphere comes from. He references a class discussion about the sources of atmospheric CO<sub>2</sub>, and tells Timothy that

we are able to “account for,” “find” and “track” the CO<sub>2</sub> emissions from humans. From here, the class moves on to something else, but Timothy remains palpably unconvinced that his theory is not a scientifically plausible explanation. This issue of identifying the sources of CO<sub>2</sub> becomes very important to Timothy later in the course, as he continues to accumulate evidence for anthropogenic climate change.

Two weeks after this conversation with Madeleine, Timothy had a discussion with me during which he changed his mind about the causes of climate change. Timothy and Jeremy were working together on their infographic final project, which they had decided to structure as a flow-chart with different pathways for people who did or did not accept anthropogenic climate change. They planned to include evidence for both sides of the climate change Conversation in their infographic. Timothy decided to use Milankovitch cycles as a piece of their pro-anthropogenic climate change evidence, but the graph he found showing Milankovitch cycles was confusing so he called me over for help. The resulting conversation took the remainder of the class period (about thirty minutes), and during it we discussed many pieces of scientific evidence and used various conceptual tools (such as an animation of the Milankovitch cycles) to explore the multiple lines of scientific evidence for climate change.

I first showed Timothy an online visualization tool of the Milankovitch cycles so that he could explore the relationship between solar forcing, carbon dioxide and temperature over time. This website has the ice core data and Milankovitch cycles overlaid on top of each other. As a user drags a cursor forward and backward in time, an animated earth goes around the sun adjusting its cycles to the appropriate parameters. Timothy was surprised and impressed by how much earth’s orbital parameters changed over time, exclaiming

“Wow, so it’s a lot!” Once he had satisfied himself that he understood the cycles, he decided that he needed a piece of evidence that showed that *current* changes in temperature and carbon dioxide didn’t correlate in the same way with the Milankovitch cycles.

This search for a piece of evidence led to another discussion of the relationship between temperature and carbon dioxide, both in the ice ages and in the present day. Timothy was aware that there was a “delayed effect” of 800 years between the time that temperature began to rise in the ice core record and the time that carbon dioxide also began to rise.<sup>7</sup> Scientists attributed this to the fact that changes in orbital parameters initiate the warming, triggering carbon dioxide-temperature feedbacks in the climate system. This historical correlation between carbon dioxide and temperature could potentially be an important intermediary step in some students’ developing conceptual understandings of climate change. Timothy reasoned that current warming showed have a similar delayed effect:

1. **Timothy:** Like, it might be that we’re, we’re-- it might actually be that we’re putting out CO<sub>2</sub> but I don't think CO<sub>2</sub> is actually part of it, because there's a difference between the CO<sub>2</sub> and the time the CO<sub>2</sub> impacts us and the time where the temperature rises.
2. **Elly:** Wait, so that's again--
3. **Timothy:** There's a difference in time of 800 years of where the CO<sub>2</sub> affects us and the temperature changes.

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<sup>7</sup> Since the enactment of this curriculum, this 800-year gap has been called into question by a new analysis that indicates that carbon dioxide does in fact precede warming in the ice core record (Shakun et al., 2012).

4. **Elly:** //But that's in the ice core data.
5. **Timothy:** Yeah, but I mean.
6. **Elly:** You just said that right now it's different because--?
7. **Timothy:** The CO<sub>2</sub>, the temperature comes first, the temperature comes first then the, the CO<sub>2</sub> (affects?) the temperature data.
8. **Elly:** So do you think CO<sub>2</sub> affects temperature at all?
9. **Timothy:** No, it does. But I'm saying that it'd be, it'd be 800 years later, after the temperature change, if something does happen.

During this discussion, I at times had difficulty following Timothy's reasoning, because he was juggling the three different pieces of the argument for anthropogenic climate change outlined at the beginning of this section. Timothy begins this excerpt by asserting that (2) may be true— that humans may be emitting carbon dioxide, but that (3) is not true— temperatures won't increase because of what he elsewhere terms a "delayed effect." He supports this argument by citing the 800-year lag between carbon dioxide and temperature in the ice core data. I point out that this is in the ice core data (i.e. that it might not be the same now). I then start to reference the fact that current warming is different from ice ages because of point (2)— that humans are causing the increase in carbon dioxide. When I ask Timothy if CO<sub>2</sub> affects temperature, Timothy indicates that he believes that temperature and carbon dioxide should be correlated in the same way that has been seen in the past, that is any increase in carbon dioxide should be seen 800 years after a temperature change. Here, Timothy is ignoring points (1) and (2), and concludes that any relationship between carbon dioxide and temperature would have to follow a similar pattern to that which

occurred in the past, i.e. carbon dioxide would always necessarily have a “delayed effect” from a temperature increase.

Once I finally understand his reasoning, I attempt to make a distinction between the carbon dioxide increases seen now and those in the ice ages. This is the final piece of evidence that Timothy needs in order to find the argument for anthropogenic climate change convincing. I begin by making the distinction between the ice ages and current conditions, and explain that in the past the solar forcing triggered the change. However, unlike the ice ages, which were triggered by Milankovitch cycles, current warming has “CO<sub>2</sub> from different places,” namely “burning fossil fuels.” After a few minutes more discussion, Timothy asks how we know that the CO<sub>2</sub> comes from humans.

1. **Timothy:** How do we know it's from humans? How do we know it's from us?
2. **Elly:** So remember those graphs that we looked at that had the radiocarbon age and the carbon dioxide in the atmosphere.
3. **Timothy:** //Yeah, yeah. But that just showed what's happening, it doesn't show there's a direct effect on earth from the cars and pollution is causing that, it doesn't show a direct effect. They just show --
4. **Elly:** //Wait, which direct effect?
5. **Timothy:** That humans are causing climate change. They just show that it, it was going up and human population went up and it could just be a coincidence.
6. **Elly:** So we looked at one graph that showed--
7. **Timothy:** I'm just saying it could be a coincidence, that humans went up.

8. **Elly:** Right.

9. **Timothy:** And so did the CO<sub>2</sub>.

In response to Timothy's question about the sources of CO<sub>2</sub>, I reference the graphs they had previously looked at about the sources of CO<sub>2</sub>. Timothy, however, makes the point that the graphs they had previously looked at in class showed an increase in carbon dioxide in the atmosphere and increase in population, but didn't show a "direct effect" between humans and climate change. That is, because the graphs only demonstrated correlation, not causation, it "could be a coincidence" that human populations and CO<sub>2</sub> concentrations went up at the same time. During this excerpt, I try to make a reference to a graph that showed radiocarbon ages— a graph that I think would answer Timothy's questions, and after he makes his point about CO<sub>2</sub> and human population, I bring this piece of evidence into the discussion. In the following excerpt from this conversation, after hearing this final piece of evidence, Timothy decides that he believes in anthropogenic climate change and begins to try to explain it to Jeremy:

1. **Elly:** And it could have been [just a coincidence], like that was a question that people asked. Like, is it actually from humans, the CO<sub>2</sub> that's in the atmosphere. So people went back and measured a whole bunch of different things about the CO<sub>2</sub>, like the radiocarbon age and some of the stable isotopes in the carbon dioxide in the atmosphere. And determined that it came from -- but you're right! That's a great question.

2. **Timothy:** //Cuz there's, there's less radiocarbon in the air so it's radiocarbon-- so it came from fossil fuels.
3. **Elly:** //Right. Yeah. It's radiocarbon dead, parts of it.
4. **Timothy:** So you're saying that it could be, that it did come from humans cuz it's radiocarbon dead.
5. **Elly:** Mm-hm. And, you know, and the stable isotopes matched the-- and a few other things, but the, that's the—
6. **Timothy:** *((says something inaudible to Jeremy))* Cuz, cuz no-- I kinda, I kinda believe that now.
7. **Elly:** *((surprised))* Really?
8. **Timothy:** Yeah, cuz if, if the, if there's less radiocarbon in the air then there's a lot of fossil fuels burning right now and the, it's kind of obvious. Sorry Jeremy. Dude-- you know how radiocarbon-- there's more of it in new, new like, it's called new, right *((to Elly))*, more radiocarbon in new substances?
9. **Elly:** Yeah. You can use the word “new.”
10. **Timothy:** *((quickly, and quietly to Jeremy)) ((inaudible))* and that the radiocarbon in the air is, is so *((inaudible))* fossils fuels. If you, if you look at all the Milankovitch cycles, all this stuff-- and this will explain it-- so if you want to look through it—

11. **Elly:** It's-- I think all your questions have been fantastic, cuz it's so complicated that to really understand what's going on, it takes a lot of time of studying it. So, yeah.
12. **Timothy:** Sometimes you have to go against what you thought.
13. **Elly:** Yeah, and sometimes you have to change your mind. And I think that happens in science all the time, where you're like: Oh my gosh, I really think this theory is correct and it turns out that you have to change that into something else.

One of my goals in talking with Timothy was to encourage him to ask these critical questions, but also to use the available scientific evidence to find answers to his questions. In this excerpt, I reframe Timothy's idea of coincidence as a valid scientific question that scientists did, in fact, investigate. I then share some of the results of these investigations, and the methods scientists used to figure out "how we know." Timothy repeats these results to make sure he understands them, and then in line 6 states that "I kinda, I kinda believe that now." I am surprised and ask for confirmation, and Timothy develops his new thinking further. With his new understanding that the atmospheric CO<sub>2</sub> is from fossil fuels, Timothy states that it is now kind of "obvious" that human emissions of CO<sub>2</sub> are affecting climate change. And, in an interesting move, he begins trying to explain the argument (in an undertone, and thus unfortunately somewhat inaudibly) to Jeremy, who remains unconvinced. I end by making a move similar to the one that Madeleine also did in her conversation with Timothy, in positioning Timothy's questioning as an important scientific practice. Timothy responds with the statement that "Sometimes you have to go against

what you thought,” indicating that he understands knowledge and opinions as dynamic, needing to be re-evaluated.

Research has previously implicated improved understandings of the dynamic epistemological view of science as a potential gain of the teaching of scientific controversies (e.g. Bell & Linn, 2002; Bell, 2004). In this exchange, by delving into the details of the scientific evidence and the social controversy, Timothy’s epistemological view of dynamic science is reinforced. In this case, I connected going “against what you thought” to the broader scientific way of knowing and being, in which scientists have to constantly reevaluate their theories and sometimes change their minds. By doing this, I try to position the work that Timothy just did as a valid scientific practice and an important scientific epistemological construct.

Timothy reiterated that he now thought that climate change is anthropogenic in both his post-test and in his exit interview. In his post-test he answered “10, Extremely sure it IS happening” in response to a 1-10 Likert scale question: “How sure are you that climate change is currently happening” and further indicated that he believed it is “Caused mainly by human activities.” When asked in the post-test if the way he felt had changed over the course of the unit, he indicated that it had, and explained in the response below:

i[sic] say this because i[sic] used to simply believe that climate change was not at all caused by humna[sic] activity, but the simple facts that the earth has gone through many things and just now, when human population on the earth was multiplied by 7 over 100 years or so, the climate of the earth went up drastically, even more than in

the past 400,000 years. It[sic] all adds up and pretty much showed me that humans are the main cause of this, whether a good or bad thing.

In his response, Timothy argues that “humans are the main cause of this,” and uses as evidence that though “the earth has gone through many things” (i.e. natural cycles), in the past 100 years the human population has been multiplied by seven and the climate has changed more than during the past 400,000 years (as shown by the ice core data). In his exit interview, I asked him about his learning process throughout the course, and in his response he expanded this post-test answer with more specific pieces of evidence.

1. **Elly:** OK, let's-- I wanna follow-up on this fact that [in an earlier question] you said that you changed your mind [about the causes of climate change]...Where do you think you started with, when you started this unit, like where had you heard about climate change, where were you and then what was process for you like during the unit?
2. **Timothy:** Well, I was at the point where I believed that humans weren't causing it, climate change. But then I looked at all the data and, you know, the Keeling Curve data, it went up from 280 to 300-- just under three hundred parts per million, at 200 minimum over 400,000 years, and then this one hundred thousand years, the first time that we know about, that we can record ha-- it's gone up to 300, like, drastically to 380. It's almost-- it's times-- it got-- you took a third of it and added it on that's how big it was. And so, that was, that was kind of like a shock

to me that that should happen I didn't realize it at first but once I show-  
- got enough evidence, and then you told me about the Milankovitch  
cycles which really helped me, cuz then I learned about more stuff and  
I'm like, OK if these are happening that's what I originally thought was  
causing it, but these are actually the cycles that were happening and  
that's what they do, so if it's not solar activity, if it's-- if it's we're in the  
middle of the, if we're just in the middle of the Milankovitch Cycles like  
it would normally be happening, but it's going up, so.

In this exchange, Timothy explains the evidence that he found most convincing about climate change, and that contribute most greatly to his conceptual change. First, he talks about the dramatic increase in CO<sub>2</sub> which “was kind of like a shock to me,” but which he “didn’t realize at first” until he “got enough evidence.” Thus, though the increase in CO<sub>2</sub> was shocking, it alone was not enough evidence for Timothy. He says that originally he thought that there could be natural cycles causing it, but that when I discussed the Milankovitch cycles with him, that helped him understand that those were the actual solar forcing cycles and “that’s what they do.” That is, there are cycles that are understood, but are not responsible for current changes. Thus, if we are just in the middle of Milankovitch cycles “like it would normally be happening” but the CO<sub>2</sub> is continuing to increase (“but it’s going up”), the change must be caused by this human-caused carbon dioxide increase that was “shocking” in the Keeling Curve.

It is important to note that, for Timothy, no one piece of evidence held the key to his understanding of climate change. Rather, he needed to work through both an

understanding of natural variability and other mechanisms for climate change, as well as the current sources of carbon dioxide in the atmosphere. This required him to explore “how we know” both how climate has changed in the past through an understanding of Milankovitch cycles and ice ages, as well as “how we know” that the CO<sub>2</sub> comes from human activities. Only when Timothy had both of those pieces, could he accept the argument for anthropogenic climate change. Timothy’s ability to evaluate and explore the scientific evidence is directly tied to the curricular design principles in play in this unit. Timothy was positioned as a developing expert in the curriculum, and allowed to design an investigation (in his case into “both sides” of the climate change “debate”) that foregrounded his own interest and budding expertise. Without these curricular elements in play, it is unlikely that Timothy would have been able to engage with the evidence in the deep way necessary for conceptual change.

Another characteristic of Timothy’s pathway through this unit, is that it was important for Timothy to have the opportunity to engage with pieces of evidence for climate change multiple times throughout the unit. The original discussions about anthropogenic climate change surfaced Timothy’s original argument that “man doesn’t cause it.” Throughout the unit, Timothy iteratively revisited and expanded his understanding of scientific evidence. The first time we discussed sources of carbon dioxide, Timothy was unconvinced. Only after he had had the opportunity to engage more deeply in the co-varying relationship between temperature and carbon dioxide, and the past mechanisms of temperature change, did he return to the question of where current carbon dioxide comes from.

Arguments against anthropogenic climate change can be developed against any of the three statements outlined earlier— that the CO<sub>2</sub> is increasing, that it comes from humans, and that it affects temperature. Different arguments, and different contradictory pieces of evidence challenge various parts of these three statements. As we saw with Timothy, someone who does not believe in climate change may have evidence against more than one of these statements, but this evidence in itself may be contradictory. In Timothy's case, we saw this in his belief that there should be a "delayed effect" of temperature on carbon dioxide levels, while also recognizing that there was a current increase in carbon dioxide concentrations. By allowing Timothy multiple opportunities to engage with the material, he was able to find ways to use the scientific evidence to answer his questions about how we know what we know about current climate change.

Finally, it is important to note that Timothy's argumentation pathway was facilitated not only by his peers but also by a series of individuals with varying degrees of expertise in the field, including his teacher, Eric, and Madeleine and myself— both of whom have specific expertise in the field of paleoclimatology and past climate change. Without access to this expertise, Timothy may not have been able to find the answers he wanted for his questions about "how we know" about past climate changes. For example, as his interest developed in natural variability, Madeleine and I were able to provide verbal explanations for the Milankovitch cycles, as well as provide access to additional resources (e.g. the animation I used). Because the climate system is so complex, it is a challenging and daunting task to be on point for answering students' skeptical questions. An implication of this work, then, is that access to individuals with that expertise (or to very good climate

science resources) is a valuable support for students as they build deeper understandings of climate change.

## 2. Samson

Unlike some of his classmates, Samson did not have a strong opinion about climate change at the beginning of the unit. His pre-test indicated that he was initially less familiar with the topic than Gareth, Walt or Luke. Samson was also less likely to engage in the classroom debates. However, by the end of the unit, Samson reported that he believed that humans were influencing climate, and his post-test scores showed that his understanding of the scientific content had increased. Samson's trajectory was likely defined by his identification as a good student, and his consistent engagement with the project work.

Samson identified as a good student and was very thoughtful and thorough in his work. On the first day of class during introductions the students were asked to tell the class something that they did in their free time that the rest of the class might not already know about them. To this Samson replied: "Homework." The class laughed and told him to pick something else that they *didn't* already know about him. Samson was also conscientious in completing his assignments— in one instance he was the only person who completed a homework assignment on ecosystem services.

While Samson did not often speak in class unless he was called on, he was engaged in the work nonetheless. For the final project he worked in a three-person group and contributed greatly to the overall end product. Samson's attitude in the classroom and engagement with the coursework indicated that he respected school as a source of information, and applied himself to learning the material.

Samson began the course not having either a firm conceptual understanding or opinion on the causes of climate change. In his exit interview, he reported that climate change was not something that was discussed at home, though his family did take some energy saving measures (such as using energy-efficient lightbulbs). Samson reported that he was aware of the media “hype” around the topic, and had some initial interest in climate change and energy efficiency due to his participation in a Lego robotics competition a few years prior to the beginning of the unit. In the robotics competition, Samson had worked on a project that he described as being about how to “improve our planet like green-wise.” He discovered as part of this project that many buildings “aren’t up to like installation code, so you’re losing a lot of heat” thus using more greenhouse gases and increasing emissions. Samson told us that this sparked an initial interest in the subject: “That’s how I really started to think about is this, like— this is kind of a growing problem and we might need to do something about it.” Surfacing prior interests, like those Samson had, and allowing students’ to build upon this expertise by incorporating student choice into the curriculum was an important design principle in the curriculum design work.

In his exit interview, Samson told us that between that competition and the beginning of the unit, he had not thought too much more about climate change, or had any other learning experiences with it. At the beginning of our unit, in a class discussion about taking action on climate change by making an investment in solar power, Samson said that he would not be willing to make an investment in solar power if he did not recoup his costs. He then identified himself, when prompted by the teacher, as “climate undecided,” that is he was undecided as to whether or not humans were influencing climate change.

Throughout the course of the unit, Samson reported that he felt that the way he thought about climate change had shifted, both in how important of a problem he thought it was, as well as his conceptual understanding of the science. In his exit interview, he reported that he felt that he now had more evidence to support his thinking about climate change, saying: “I was kind of on the fence before. Now I know a lot more so I can, you know, get to conclusions a lot easier than [*sic*] before.” Similarly, in his post-test, Samson reported that the way he thought about climate change had changed:

Yes i [*sic*] have changed some ideas about global warming, some of the evidence really does show you that global warming is happening, or at least the increase of CO<sub>2</sub> is causing some things to happen.

Because of this new evidence, Samson has moved from being “on the fence” or “undecided” to being more certain of human influences on climate. Samson’s post-test scores showed improvement over his pre-test scores on the science content questions, indicating that he had developed a stronger mastery over the evidence for climate change. This was further demonstrated in the nuanced way that he answered a post-test question that asked what the students thought was the main cause of climate change. The students were given the options of attributing current climate change to either natural variability or human influences, or other. Samson marked other, explaining that it was: “Caused by humans adding on to the natural changes in the environment.” In the context of the curriculum and class discussions, we interpret this answer to mean that Samson is aware that natural

variability is always ongoing in the climate system, but the humans are now “adding” their own contribution on top of that, influencing changes in the climate.

### 3. Walt

From the beginning of the class, Walt identified himself as someone who believed climate change was happening and that it was human-influenced. In his exit interview he attributes his initial conceptions of climate change to *An Inconvenient Truth*, and in class mentions other media sources that have talked about climate change (e.g. on the first day of class Gareth and Walt mention a *South Park* episode related to climate change). In this excerpt from his exit interview, Walt talks about how by the end of the course, he had a better understanding of the evidence for climate change:

1. **Walt:** I knew it was happening, I knew it was caused by humans and I just have more reasoning behind it now. And I know why the opposition thinks why-- thinks it's not, and how-- and the evidence that counters that and so how, so I can really hold like a debate about it now.
2. **Researcher:** So, can you talk a little bit more about what the evidence is that?
3. **Walt:** Um, well, some of the evidence we learned is we know that it is found in science itself that CO<sub>2</sub> is a greenhouse gas so it will cause the earth to warm because of what it does just as a molecule itself and so even if-- so one of the major arguments against manmade global warm-- or manmade climate change is the lag in the CO<sub>2</sub>

behind the temperature but even if that's the past, things-- there's never been this amount of CO<sub>2</sub> being put into the atmosphere all at once so history can't really, we can't really look at history and be like, oh look, this is what the trends are, we have to look at what the science behind it is and what the current events are, and so when you look at that you see that there's-- although it's a natural occurrence for there to be spikes in temperature, they've never been in a short amount of time and continuous like what we have right now.

Walt begins by saying that he now has more evidence not only to support his own argument that climate change is “caused by humans” but also the reasoning behind “the opposition” and “the evidence that counters that.” Walt has thus been able to strengthen his own argument for human-caused climate change by increasing his ability to refute counter-arguments. In response to the researcher’s question about what evidence in particular Walt finds compelling, Walt describes that mechanism of the greenhouse effect on a molecular level, and counters an argument about natural variability by pointing at differences between past and current change. He states that the natural variability argument is invalid, that is “we can’t really look at history” and past “trends” because the character of current events is different (the current “spikes in temperature” are “in a short amount of time and continuous”).

In his description of evidence for climate change, Walt refers twice to the authority of “science” on the issue. This epistemic move indicates that Walt’s personal epistemology

holds “science” as an authority. First, when talking about the greenhouse effect, he states that this evidence is in “science itself.” He invokes science a second time when talking about how we have to “look at what the science” behind current events is. This indicates that Walt is privileging a scientific way of knowing, that he is accepting what “science” says is happening. The phrase “science itself” is interesting in that he refers to an accepted body of scientific knowledge as a trustworthy entity. It is unclear what Walt would accept as “science itself.” Here he uses it to refer to a basic chemical principle (the absorption of infrared radiation by polar molecules). It is possible that he would not ascribe the same level of privilege to other kinds of science, such as the Keeling Curve observations of carbon dioxide.

Walt’s alignment with “science itself” was apparent in his participation in classroom activities, as well. He would often support the argument of human-caused climate change in debates with Luke, Jeremy and Timothy. In particular, during the Nov. 7<sup>th</sup> debate discussed in the other case studies, while Timothy, Luke and Jeremy challenged the evidence the teacher and researcher presented, Walt would respond to comments that those three made, often turning around in his chair to talk to them. Throughout this process, it appeared that Walt was getting increasingly frustrated with his classmates.

Walt interjected at several points. For example, at one point, the researcher asked Luke about what “we know about what one of the major causes of global warming is.” Luke responds with “We don’t,” but is quickly interrupted by Walt who says: “Yeah we do” in an annoyed voice. A few seconds later, when the idea of “no direct connection” between people and warming is brought up, Walt turns around to Timothy and Jeremy’s table and says: “But we still know CO<sub>2</sub> is a greenhouse gas that causes global warming.”

About a minute later, the following exchange takes place while discussing a graph showing an increase in human CO<sub>2</sub> emissions throughout the 20<sup>th</sup> century.

1. **Researcher:** Right. So: o, the: en, say again what you said, the reason for why you don't think it's humans?
2. **Luke:** Because there's no evidence that links greenhouse gases to global warming except that graph so, um, that graph is the only evidence that people have the CO<sub>2</sub> has caused global warming.
3. **Walt:** *((loudly))* Besides basic science!

The researcher asks Luke to repeat an argument he's made against human-influenced climate change. Luke cites a lack of evidence for climate change beyond that graph, and Walt counters Luke's assertion that there isn't any other evidence for climate change, with the evidence of "basic science," which one can assume in this case means the existence of a greenhouse gas effect. Luke is looking for a single piece of evidence that can connect human output of carbon dioxide to increased temperatures, and is not satisfied with the current evidence because it only shows human output of carbon dioxide, and doesn't make a connection to temperature. In his interjections, Walt is drawing attention to the fact that the connection between increased carbon dioxide and increased temperature comes out of "basic science" because "CO<sub>2</sub> is a greenhouse gas that causes global warming," that is he is making the connections between the three components of the argument discussed in Timothy's case. The fact that his classmates are ignoring what, to Walt, is an important piece of evidence—this "basic science"—is frustrating.

*Discussion of Scientific Influences*

Despite the prevalence of politics or other ideological influences in the classroom, ultimately for students such as Timothy, Samson and Walt, a deepened understanding of the multiple lines scientific evidence for anthropogenic climate change was the primary factor in ultimately accepting or rejecting the scientific consensus view of anthropogenic climate change. Timothy and Walt share similar characteristics in that they both enjoy debating, both challenge themselves, both value scientific knowledge, and both began the unit with an opinion on climate change that was more tied to their familial or political ideology than the scientific evidence. Though they began the climate unit on opposite ends of the political spectrum, their pathways through the unit were characterized by a desire to further their own understandings of the scientific basis for natural or anthropogenic climate change. It was Timothy's desire to understand the entire body of scientific evidence around "both sides" of the Conversation that eventually led him to realize that the scientific evidence for anthropogenic climate change was, in fact, more extensive than that for natural variability.

It is unsurprising that Timothy initially believed that "we don't know" what caused climate change. Studies have shown that despite the agreement in the scientific community, there is still a prevailing belief among the general population that the causes of climate change are still heavily debated among the scientific community (Leiserowitz et al., 2011). This perception has been partially attributed to the media's tendency to give both sides equal weight in their coverage of climate change topics (Galef, 2010). In addition, the

complexity of the climate system and the fact that weather and climate are easily conflated, also makes it difficult for learners to reason about climate science.

Both Timothy and Luke had difficulty with reconciling their expectation of a single piece of evidence that “proved” anthropogenic climate change with the reality of the accumulation of multiple lines of evidence. In order for Timothy to conceptualize this scientific corpus of evidence, he needed multiple opportunities to ask questions about the evidence, create his own hypotheses about the causes of climate change, and test these hypotheses against the body of scientific evidence.

For both Timothy and Gareth, it was important that they were able to engage not only with the scientific evidence of the consensus view, but also with the evidence of those who attribute climate change to natural variability. This desire to see “both sides” may be a unique challenge for the teaching and learning of climate change science. For topics such as cellular respiration or astrophysics that are not embroiled in a social controversy it is unlikely that a student would challenge the consensus scientific view in the same way or be as interested in competing theoretical accounts and models. Even in topics such as evolution that have a similar social context, the arguments against the teaching of evolution are mostly seeded in faith-based objections, not in a belief of an opposing and equally valid scientific theory. In American society, however, there is a public perception that there are two valid scientific theories at odds with one another, and this perception affected how all of the case study students approached their own evaluations of scientific evidence.

While the challenges this social context cause are apparent, this can also be seen as an opportunity to deeply engage learners in more fully participating in scientific ways of knowing, doing and being. For example, the scientists, teachers and researchers involved

in this unit framed Timothy's challenging of the scientific evidence as an authentic scientific practice of asking critical questions, testing scientific knowledge, constructing arguments, and drawing evidence-based conclusions. The scientists who visited the classroom told us that they were impressed with the level of reasoning Timothy showed in his final infographic presentation. To them, Timothy— who presented both sides of the climate change controversy in his final project— sounded more “scientific” than many of his peers, precisely because he was challenging evidence and critically engaging with the data. Even if Timothy had *not* ultimately changed his mind, he still would have continued to develop his expertise in these valuable scientific practices. Educators can support learners who challenge the consensus view to deepen their participation in scientific processes, no matter what views these learners ultimately adopt. In this way, Timothy's experience aligns with research on the benefit of teaching scientific controversies and debate that demonstrate that providing students with opportunities to engage with evidence on multiple sides of complex, interdisciplinary, social controversial topics can support students epistemological views of science as dynamic, and help support understandings of the role of debate and controversy within the scientific community (Bell, 2004; Bell & Linn, 2002).

Despite these opportunities, there is no question that the teaching and learning of socially controversial science is challenging, especially given the wealth of skeptical arguments that draw on small pieces of the data corpus as evidence against anthropogenic climate change. Just in this unit, a multitude of evidence to support contrarian arguments surfaced, from the 800-year gap between carbon dioxide and temperature in the ice core data to the fact that carbon dioxide is a small percentage of the atmosphere by volume. All

of these pieces of evidence are scientifically accurate according to the best consensus understanding, but can be used out of context in ways that are misleading or do not align with the consensus view. In addition, students bring in their own ideas (such as Timothy's speculation of a million year cycle) or unverified arguments (Luke's father's article about cooling in the near future). For teachers to whom climate science is a new field, supporting student engagement in the science given the enormous corpus of evidence for and against climate change may be a daunting task. To address these concerns, I suggest that there is an urgent need for professional development to support teachers in climate change science. Teachers, like the case study students, likely have a wide range of experiences and initial understandings about the standing of climate science within and outside of the scientific community. Like the students in Eric's class, teachers also need to have the opportunity to explore the scientific evidence and engage deeply with the social and scientific dimensions of the topic.

Timothy's process of critically questioning, struggling with, evaluating and drawing conclusions on the scientific evidence was greatly supported by his access to others with deep disciplinary expertise. Timothy's interactions with paleo-climatologist Madeleine and myself, a former ocean scientist, were fundamental to advancing his reasoning about scientific evidence for climate change. It is unlikely that without the support of myself and Madeleine, and our familiarity with Milankovitch cycles and the chemistry of atmospheric carbon dioxide, Timothy would have been able to engage at the same level with the material, and may not have ultimately accepted the consensus view as he did. This was an important aspect of the curriculum model, which strategically connected students to working experts in the field to help support students participation in authentic scientific

questions and practices. In addition to the conceptual expertise these experts can provide, they are also important relational components of these interactions, such as the building of trust between scientists and students that further support student investigations in science.

This analysis suggests that successfully supporting student engagement in the evidence for climate science requires the participation individuals with deep disciplinary expertise. At this point, most teachers do not have a depth of subject matter expertise specifically in climate science, given the new nature of the science and the interdisciplinary nature of the endeavor. To support teachers in this way requires the participation of those who do currently have the necessary disciplinary expertise, specifically those working in fields related to climate science. Connecting learners to disciplinary experts in the pedagogical model of this unit highlighted the role for scientists to support the teaching and learning of climate science both through curriculum design partnerships with educators to create professional development materials, as well as, like Madeleine, interacting directly with teachers and learners as they engage with the material.

### **Conclusions and Future Directions**

In this study, I explored how learners approach the study of climate change from within a socio-political context of controversy. Whether it is listening to Rush Limbaugh with a parent or commuting in a Nissan Leaf, initial perceptions of climate change are influenced by the climate change Conversation and the ways of being, knowing and doing associated with various voices in this exchange. Ultimately, learners' pathways are shaped not only by their developing understanding of the scientific evidence, but also by the

political and social influences that learners navigate across the contexts of their lives. This study suggests that it is important to allow students space to voice their socio-political identifications as they wrestle with the scientific evidence supports students learning of climate change science.

For students like Luke and Timothy who don't identify initially with climate change, or see climate science as conflicting with ways of being that they value in their own lives, providing role models of those who successfully navigate the tensions between political belief systems and the body of scientific knowledge may be beneficial. This is consistent with work done with religious communities (Hitzhusen, 2010) and wildlife agencies (Coyle, 2010) in which aligning climate change messages with existing belief systems supported both the learning of climate science and activation for action on climate change issues.

Climate change educators need to understand and support students' as they interact with climate change across the contexts of their lives. This study was narrow in scope, in that it focused on only five male students from a relatively homogeneous, middle-class population. More work is necessary to describe the range of influences that might be in play for male and female students from diverse economic, political, geographic and demographic backgrounds. Research is needed to understand the concerns of particular communities and how those interact with students' participation in climate change solutions. As a research community, we have an incomplete understanding of what influences learners' perceptions of climate change, how those perceptions are supported or challenged through climate change curricula, and how we can support students as they negotiate tensions between their personal, political and scientific ways of knowing, doing and being.

There is a tendency to approach climate change education with a focus on those learners who, like Timothy and Luke, are vocal in their disagreement with the scientific consensus. As this study showed, there are gains to be made by deeply engaging these students in the scientific evidence for climate change. However, this requires a large investment of time and resources, and means that other topics and concepts will receive less attention. Students like Samson, who had yet to position themselves for or against the scientific consensus view in general required less commitment of instructional time and resources. It might benefit the educational community to consider focusing more attention in the middle of the Six Americas—those students who as of yet are, like Samson, “climate undecided.” This is especially important given that those who fall into this climate undecided, or Disengaged, are more likely to be from higher poverty areas (Maibach et al., 2009) that will have the most difficulty responding to climate impacts on resource availability (IPCC, 2007; NAS, 2009).

We need to focus on preparing teachers to face the challenges of teaching climate change in their classrooms. We are facing a large professional development effort in the coming years with the advent and implementation of new science standards that will likely be adopted by collections of states. Climate change science is included in the framework driving the development of new standards (NRC, 2011); it would be unethical of us as a community to hold teachers accountable for teaching these standards without providing sufficient professional development and instructional resources and support. To accomplish the gains seen in this study required a deep scientific expertise and an up-to-date and nuanced understanding of the evidence for climate change. Teachers also needed support in helping students negotiate the societal and scientific implications of climate

change and working effectively with students in this controversial context. When attending to these factors in a coordinated effort, it is possible to make significant shifts in students' understandings of climate change science, even in students who were initially very resistant to the topic. In addition, the learning that occurred in the classroom crossed out of the classroom into the students' homes, shaping family talk. This important outcome further emphasizes the benefits of supporting K-12 learning of this pressing global issue. Supporting climate change education in our schools will require the collaboration of learning scientists (educational researchers), natural scientists and teachers engaging in effective partnerships to promote student participation in climate change science and decision-making.

This study also demonstrates the importance of having individuals with deep disciplinary expertise available to engage with learners. Because of the complexity of the subject matter and the breadth of the evidence for and against anthropogenic climate change, novices in climate science may find it difficult to conceptualize the body of scientific work. Supporting teachers in their own understanding of climate science and the social controversy through professional development will help them in turn support their students' learning. Developing programmatic models that connect these students and teachers to disciplinary experts will further support the teaching and learning of climate change science within this heated socio-political context.

To move forward in K-12 climate change education, there is a need to develop models in which networks of experts can support teachers and students as they engage with these complex scientific ideas. A key design principle of the unit described here was connecting students to disciplinary experts working in the fields of climate science and climate

impacts, and this connection proved important to students like Timothy in their developing conceptual understandings of climate change science. Disciplinary experts, then, need to be supported for this level of participation in K-12 instruction, and may need assistance in deepening their understanding of the teaching and learning of science. In order for these partnerships to work effectively, students and teachers also need to be prepared to work with experts who may have particular expectations for student learning and student work from their own participation in scientific cultures. In the last two chapters of this dissertation, I address these issues, by exploring scientists' participation in curriculum design and enactment, and the challenges and opportunities of these partnerships.

## Chapter 3

### **Climate Scientists' Participation in Educational Activities: Leveraging Scientific and Pedagogical Ways of Knowing, Being and Doing**

#### **Introduction**

Scientists recognize that they have an important role and interest in increasing public awareness and understanding of contemporary science and scientific processes (e.g. Bowman et al., 2010; Cameron and Chudler, 2010). Encouraging the participation of scientists in science education is important as scientists can provide valuable and detailed content expertise, experience with and knowledge of scientific practices and processes, as well as entry points for learners into scientific communities. In addition, scientists can provide access to the most recent scientific data and understandings about societally relevant contemporary science for areas that need a quick public response, like climate change. Despite the importance of scientists in science education, few studies have attempted to systematically describe the constraints and affordances of their involvement, or how their involvement can be optimized and supported by educators designing learning environments.

This study examines climate scientists' participation in a high school climate science curriculum development project. I describe scientists' motivations and strategies for engaging in educational work, and explore how scientists leverage scientific and pedagogical expertise through their participation in curriculum development. This work

provides the beginnings of a foundation for considering how to utilize and support scientists' involvement in education.

There are many ways that scientists can and have been involved in science education, from curriculum development to participating in formal or informal settings. Rudolph (2005) outlines the historical influence of high-profile scientists in introducing laboratory skills and procedures to the science classroom. Rudolph (2002) argues that scientists involved in the curricular efforts of the Physics Science Study Committee and the Biological Sciences Curriculum Study participated in the hopes of promoting a more realistic public conception of the scientists and scientific endeavors. Linn, Songer & Eylon (1996) discuss the period since the 1970s as one of partnerships in science learning and instruction. They describe the need for interdisciplinary teams of disciplinary experts, educational researchers, learning scientists, technologists and teachers in innovative curriculum research and design. Natural scientists have also played a role in science education through scientist-educator or scientist-student apprenticeship programs (e.g. Barab and Hay 2001; Drayton & Falk, 2006; Hsu, Roth and Mazunder 2009; Sadler et al. 2009; Varelas, House & Wenzel 2004). While Drayton & Falk (2006) did examine the experiences of both the teachers and scientists in an effort to understand dimensions of successful partnerships, much of this work has focused on teachers or students as the learners in these settings, and not the scientists. Scientists are cast as the "experts" in educational scenarios. However, if educators are to productively engage in public participation in contemporary science, a deeper understanding is required of the needs scientists have as learners in educational environments.

Research has described some of the issues relevant to science communication by

scientists. For example, climate scientists have been criticized for focusing too much on scientific debate or uncertainty (Galef, 2010; McBean & Hengeveld, 2000), being reluctant to take on an advocacy role (Fischhoff, 2007), and using complex or confusing language (Nerlich, Koteyko & Brown, 2010; Somerville, 2011). Research has also explored how experts and novices have differential organizational and retrieval mechanisms of information that may lead experts to have trouble anticipating challenges for novice learners, a phenomenon termed an “expert blind spot” (Nathan, Alibali & Koedinger, 2000, 2001; Nathan & Petrosino, 2012; Schmidt & Cansler, 2006).<sup>8</sup> While supporting scientists’ effective communication with the public is doubtless challenging, focusing on what scientists are failing to do begins to sound alarming similar to deficit perspectives of learning. Here, I reframe the issue of scientists in education, asking: (a) what scientific and pedagogical expertise do scientists bring into their educational efforts, and (b) how can educators and educational researchers support scientists developing expertise about science learning and educational practices?

This study highlights the varied prior experiences and expertise that climate scientists drew on while developing a high school climate change and climate science curriculum. This analysis not only shows how strongly scientific values and practices are leveraged in this group of climate scientists’ educational work, it also demonstrates how the climate scientists’ own experiences as educators and students inform their participation. This transfer of scientific ways of knowing, being and doing into a new arena is an example of how prior modes of participation are leveraged in a new context. In addition, this work describes the types of pedagogical tools that scientists bring to

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<sup>8</sup> For a more thorough examination of expert blind spot, see Chapter 4 of this dissertation.

curriculum design work. This has strategic implications for how scientists and educators can work together in designing learning environments.

### **Theoretical Framework**

For this analysis, I draw on Herrenkohl and Mertl's (2010) framework of ways of *knowing, being and doing*, to explore this idea of navigation of multiple communities<sup>9</sup>. This framework of knowing, being and doing is a concise way of describing an individual's holistic and dynamic participation in social contexts. Herrenkohl and Mertl describe ways of *knowing* and *doing* as the "valued social and cultural activity" that include conceptual and epistemological dimensions of learning (p. 7). In this analysis, I use ways of *knowing* to describe what is known, how that knowledge is constructed from what kinds of evidence, and what kinds of knowledge is valued. Ways of *doing* describe the ways individuals actively participate in particular practices. Ways of *being* are described as individual's patterns of action that arise from affective and value-laden negotiations of particular social contexts, such as "interests, motivations, emotional commitments, and personal and social values about what is worth learning and how or why one ought to put certain knowledge and skills into practice" (p. 7)

As a cultural group, the scientific community is associated with particular ways of knowing, being and doing. Scientific ways of knowing privilege knowledge that is collaboratively-constructed and grounded in systematic observations and analysis (Latour, 1986; Latour & Woolgar, 1987). Scientific ways of doing included practices that enable

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<sup>9</sup> Further description of the framework of knowing, being and doing is included in Chapter 2 of this dissertation.

scientists to create, evaluate and communicate scientific knowledge. Research has explored the unique discursive practices of science, and the support students require in appropriating these scientific norms for participation in the scientific enterprise (NRC, 2007). For example, Lemke (1990) strongly argues that science has its own language, and that learners need to gain proficiency not only in the scientific vocabulary, but also in how scientific terms are used to make meaning in scientific work. The scientific community also has a set of values, interests and norms (e.g. valuing objectivity, curiosity and critique) that encompass scientific ways of being.

This is not to suggest that all scientists or communities within the sciences participate in scientific activities in the same ways. For example, Knorr Cetina (1998) explores the differences in epistemology and practice of scientists in biology and physics labs. There can also be differences across universities and national cultural contexts (e.g. Traweek (1988) discusses variations in the activities of particle physicists in the United States versus Japan) between different research groups within a university, or between different individuals within a lab.

Consensus research reports on science learning emphasize the multiple dimensions of scientific learning and scientific work. These include not only understanding and using conceptual knowledge, but also participation in and reflection on practices and processes that lead to the creation and communication of new knowledge: argumentation, using evidence, making observations, collecting data, etc. (NRC 2007, 2009). The recent NRC *Framework for K-12 Science Education* focuses on the notion of “knowledge in practice,” that is contextualizing knowledge in authentic scientific practices (NRC, 2012). This framework includes cross-cutting scientific and engineering practices as the first of three

dimensions, and lists the following eight science and engineering practices as “essential elements” of K-12 educational experiences:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence (NRC, 2011, p. 3-5)

In addition to these practices as generalized ways of doing, specific scientific communities may have additional characteristic ways of doing. For example, some communities of scientists may have particular ways to engage in the practice of communicating science: giving weekly seminars, holding research group meetings, attending particular conferences or writing and submitting articles to particular journals.

I use the framework of knowing, doing and being to describe how scientists drew both on ways of knowing, being and doing associated with the scientific communities to which they belonged and those associated with their experiences as teachers and students when participating in a curriculum development project.

## **Methods and Study Design**

### *Study Context*

The context for this study is a climate scientist-led development of a dual credit high school climate science course. Climate scientists in this study are members of the Climate Change Group (CCG) is an informal organization of faculty, graduate students and post-doctoral fellows who study climate science at a large research university. The CCG was first funded and formed in 2001 with the goal of increasing interdisciplinary collaboration and education among scientists studying climate-related topics. As there is no formal climate science department at the university, the CCG serves the role of bringing together scientists whose research or interest lie in scientific areas that relate to climate.

The CCG has also served as facilitator for climate scientists interested in engaging in outreach with the general public. The development of the dual-credit high school course is the first funded education/outreach project of the CCG. The class is based on a sophomore-level college climate science course in the atmospheric sciences department at the university. This course is “dual-credit,” that is high school students enrolled in this course would receive credit from the university in addition to high school credit.

The curriculum is being adapted almost entirely by the climate scientists, with an advisory board of scientists and educators. Given that scientists spearheaded this effort and sought, in part, to promote student understanding of authentic scientific practice, there are some parallels between this project and the scientist-initiated reforms of the 1960s (Rudolph, 2002). This opened up the question of whether the curriculum created by the scientists in this study would potentially face similar issues as those in the 1960s, or

whether a team of interdisciplinary scientists would take a different approach to curriculum in the current scientific and educational cultural moment.

During the first year of the program, ten high school teachers were recruited to participate in professional development for the course, with the aim of creating a community of scientists and educators interested in promoting climate science education. About ten graduate students from the CCG were recruited by the faculty to work on components of project-based investigations for the course. Some of these students participated for credit in a graduate certificate program, some were volunteers and a small number were partially funded by the project.

### *Researcher Positioning*

I began my graduate career in the oceanography department at this university and as such was a member of the CCG for five years before this study began. Since leaving oceanography, I have remained in contact with the group, and have personal relationships with many of the members. In addition, I was partially funded by the grant for this course to act as an educational consultant for developing the course, and in particular to aid graduate students as they created activities. In some ways, this insider status provided me greater access to the community, and greater insight into the meanings of these activities within the community with which to approach the writing of an ethnographic “thick description” (Geertz, 1973). For every ethnographic researcher there exists a tension between observing the activities within the study in a distanced way versus becoming immersed in everyday life in order to fully understand the culture. Emerson & Pollner (2001) describe this as where to put the slash in “participant/observation,” wherein

ethnographers position themselves somewhere along the spectrum from participant to observer, with challenges arising wherever they decide to work. In my case, my “slash” was closer to that of participant than observer. As an ethnographer with a high “participant” or “insider” status in the community, I made a systematic effort to make explicit my own preconceptions and attitudes, and to keep them in mind during the analysis and writing of this study. To increase the rigor and maintain the validity of the research, I triangulated the data through as many data sources as possible, communicated about my findings with other researchers as I progressed, and had other researchers view and comment on the data.

#### *Data Sources and Analysis Strategy*

Participants include ~20<sup>10</sup> scientists (graduate students and faculty), and 10 high school teachers. I collected data from Spring 2009 – Fall 2011, including audio- and video-recorded observations of curricular development meetings, professional development workshops, and semi-structured interviews with scientists and teachers; curricular artifacts, personal reflections by the scientists, survey data from the workshops, and qualitative ethnographic field notes (Nespor, 1996).

All audio and video-recordings were reviewed, and significant moments representative of trends in the data were identified and selected for transcription and further analysis. Transcribed audio and video data, field notes, reflections and artifacts

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<sup>10</sup> This number is given as an approximate value due to the range in the depth of participation of scientists in the curriculum development project. While there were as many as 40 scientists involved, most of these had a very low level of participation; with a core group of around 10 scientists who had the most influence on the analysis.

were analyzed using an emergent strategy to identify key themes (e.g. Lofland & Lofland, 1995). I began by identifying specific practices the scientists engaged in (e.g. collaboration, collecting data, etc). After noting the number of relevant scientific ways of knowing, being and doing that were apparent in the data, I went back through the data looking for practices associated with scientific work as laid out in the *NRC Framework for K-12 Science Education* and consensus reports on science learning (NRC, 2007; 2009; 2011). Finally, I examined the data for ways of knowing, being and doing not generally associated with the educational community, in particular focusing on those related to pedagogy. After repeated reviewing of this data corpus, assertions were generated and tested by finding key linkages in the data. I used memos to tie together connected pieces of data and begin describing patterns and themes in the data corpus; I used triangulating evidence from various data sources and searched for confirming and disconfirming data, as described by Erickson (1986). After the analysis was completed, I spoke with various key informants as a member checking process.

## **Major Findings**

### *Overview of the Project*

In this analysis I describe how scientists draw on values, practices and knowledge (being, doing and knowing) from modes of participation in other communities when engaging in new educational practices. I begin by documenting the motivations for and goals of a curriculum development program that was funded and led by climate scientists, and examining how these were consistent with the CCG's cultural values and practices. I then describe how aspects of this curriculum project were taken up by particular members

in ways that were consistent with their own participatory systems. In particular, I attend to how scientists' participation is similar to and deviates from their learning practices as scientists, and present an example in which the process of creating an activity to demonstrate the Greenhouse Effect (GHE) mirrored an authentic scientific inquiry process, through iteratively framing scientific questions (What is physically and chemically happening during this demonstration?), devising and carrying out experiments to test theories, collecting data, analyzing results and constructing evidence-based conclusions, all within the context of the relevant scientific body of knowledge.

#### *Establishing goals for the curriculum project*

In 2009, professor Margaret, in conjunction with CCG coordinator Lilian began adapting a Northwest University (NU) sophomore-level atmospheric sciences course (Atmospheric Sciences 211: *Climate and Climate Change*) for high school. They partnered with a program at NU that allowed local high school students to get NU college credit for taking these courses (NU in the High School, or NUHS). There were three main objectives of this project that became clear in the early discussions:

1. Creating a community of scientists and educators interested in promoting climate science education.
2. Funding and otherwise supporting graduate students to create sustainable projects to communicate climate science.
3. Demonstrating to high school seniors that climate change is a quantitative, high-level science, and introducing high school students to potential career

trajectories in climate science.

At an early meeting with the graduate students, Margaret described two of the major goals of the grant proposal: creation of a community and development of curricular modules. From the inception of this project, Margaret and Lilian approached the task of creating the high school course as one that was necessarily collaborative with high school teachers and others with pedagogical and educational expertise. Margaret and Lilian felt that the scientists involved in the project lacked the experience and pedagogical knowledge necessary to create a successful high school course. While the scientists had a range of experiences with teaching, creation of curriculum and outreach (one graduate student had formally been a high school teacher), they generally felt that in order to successfully adapt Atmospheric Sciences 211 into a NUHS course, they would need input from others with the appropriate expertise. In addition, Margaret and Lilian hoped that through this process, they would establish a sustained community activated for climate science education.

Margaret also outlined a second goal of creating and adapting curriculum modules using authentic scientific data and resources. Graduate students who were part of the CCG's active outreach program would ideally do much of this work. Historically, CCG outreach activities tended to be one-off events— for example, one might give a presentation at a community center or school. Recently, Margaret and others within the CCG had been working to make the work of the outreach group more sustainable, and the creation of this course was one way to accomplish this.

The final objective of the course was to bring high school students in to climate science in an engaging way, and to open up environmental science as a possible career pathway. Through discussion with high school teachers, administrators, and the project's

board, Margaret learned that earth science was often used as a credit make-up class for high school students. While earth science can be taught in a rather qualitative fashion, climate science as practiced by scientists is a mathematically rigorous enterprise. Margaret was thus interested in attracting upper-level students— those who would take AP Chemistry and Physics— to earth science. In addition, she wanted to provide opportunities for students to have early exposure to earth science, as like many climate scientists, Margaret began her career in a different field before transitioning into climate science. Faculty and graduate students alike remarked on multiple occasions that they did not have the opportunity to take climate science until college or even graduate school, and would have liked to be able to learn about it earlier in their careers.

In part, this focus on engaging upper-level students in climate science in a quantitatively rigorous way was a reaction on the part of scientists to attacks on climate science as an endeavor in the public arena. Climate deniers denigrate climate science as “junk science.” The scientists in this study wanted to show students who were already interested and engaged in quantitative science that climate science was a viable alternative. However, the teachers involved in the project taught students from diverse backgrounds, and many discussed with the scientists how to ensure the appropriateness of the curriculum for a broader audience. While the scientists were very willing to think about these issues, equity and broadening participation in science was not one of their main objectives and this will ultimately have unintended consequences in further limiting the audience that has access to participation in climate science through the curriculum. It reflects decades of similar approaches to science education that have sought to identify and cultivate the “best and brightest” in science, rather than focus on strategies to engage

learners from all backgrounds. Rudolph (2002) characterizes the aims of some university scholars in the 1960s design efforts as seeking to “reestablish academic standards...demonstrated by the grossly inadequate intellectual preparation of the first-year college students” (p. 25). Similarly, the scientists in this study wanted to raise the academic bar for students entering into their scientific field. However, though the scientists sought to target a new audience for climate science, by focusing students who were already positioned to enroll in AP classes, they narrowed their potential audience significantly. While the ultimate goal of increasing student engagement with climate science as a quantitative science has merit, doing so without attending to issues of access and privilege will reinforce existing barriers in science education.

During the first meeting with the teachers in February of 2011, Margaret related an anecdote that synthesized the three different goals for the project. She had gone to a business lunch for high school girls through her work on another project that promotes participation of women in science. There, she met and spoke with a student who had previously taken the NUHS course Marine Biology, and was currently in the NUHS Oceanography course (Ocean 101). This conversation helped Margaret think about what exactly the Climate Change course should look like and how that could be accomplished, which she articulated in an early meeting with the high school teachers:

**1. Margaret:** [I] talked to someone in NU Ocean 101...She'd taken Marine Biology and then she'd took Ocean 101 and, um, she said, “Well it's ok but it's just a lot of PowerPoint slides, lectures”. And...it was good feedback for me because when I open this up, is we really want this to be a partnership. [Grant, a professor] has a

thousand PowerPoint slides on his website, you can download today, um, but obviously that's not going to work for your [high school] kids.

Margaret wants to engage college-bound youth, like the student in this anecdote, in climate science. Through her conversation with this student, she realized that the standard format of the Atmospheric Sciences class— PowerPoint lectures— was not going to be engaging for the audience, as the student compares Ocean 101, which is mainly taught via PowerPoint to her NUHS experiences with Marine Biology, which had been more active and engaging. The current Climate Science course exists as an enormous library of PowerPoint slides (Grant, a professor who has previously taught the NU course says that at one point he counted up his slides and found he had over 1200 of them), and that is how the course is taught to 90 NU sophomores. However, this conversation helped Margaret recognize that this lecture approach needed adjustment to make it appropriate for high school students. Creating engaging high school curriculum is not a practice or way of doing with which the scientists felt comfortable, which is why Margaret emphasizes that “we really want this to be a partnership” between the teachers and the scientists. This desire to make the course active and engaging in addition to the aim of bringing authentic scientific data into the high school classroom is what led to the decision to make the development of “hands-on activities” a central focal point of the work of the project. In order to successfully develop these activities, the scientists partnered with the high school teachers and myself, as an educational consultant, who could help support them in these new pedagogical ways of knowing and doing.

In my role as an educational consultant, I provided some input into research

consensus on science learning and teaching. While some participants and/or activities tracked these ideas closely-- for example graduate student Madeleine thought deeply about the six strands of science learning while creating her activity on ice cores—the curriculum design project as a whole was not deeply embedded in research on science teaching and learning (NRC, 2009). Instead, the curriculum design decisions were guided by scientists' own experiences in the classroom and significant input from the high school teachers as to what would or would not “work” in their classrooms. In general, the design work followed an iterative approach, in which curricular resources were created in full or in part by scientists, then shared with teachers during professional development workshops. Teachers provided significant input at these workshops, and scientists revised the activities based on this input. In some instances, scientists piloted activities in classrooms or partnered with teachers to revise specific aspects of the activities.

In the articulation of the content goals and the structure of the class, there is evidence of scientists' drawing from scientific ways of knowing, being and doing, and appropriating and extending these into new modes of participation. In setting up the project, the scientists placed a value on quantitative earth science, graduate student support and education, in addition to high school education, collaboration and networking between educators and scientists. This set-up is consistent with the general structure of the CCG itself, which supports graduate student education, works toward development and education of quantitative climate science on a college level, and is geared toward creating a collaborative, interdisciplinary community. In addition, through collaborating with educators, listening to students and reflecting on their own experiences as teachers and learners, the climate scientists were able to develop and leverage pedagogical ways of

knowing, doing and being.

*Leveraging the ways of knowing, doing and being of scientific communities in educational work*

Climate scientists drew on many of the scientific ways of knowing, doing and being as they constructed the high school climate course. That is, scientists' scientific values, practices and understandings that are brought to bear in their scientific processes were also in evidence in their educational work. They appeared both in the overall way that the course development process was structured as well as in specific curricular development events. This section details the scientific ways of knowing, doing and being that were most in evidence in the scientist's work throughout the curriculum development process as a whole. At the end of this chapter, I explore in detail a meeting about a greenhouse gas demonstration to show how these scientific ways of knowing, being and doing manifest in a specific activity development event.

CGU scientists participated in many of the scientific practices outlined in the *NRC Framework for K-12 Science Education* during this curriculum development effort. In addition to these scientific practices, or ways of doing, I also identified a variety of other ways of knowing, doing and being leveraged by scientists in their educational work that were also characteristic of scientists' scientific work. These included using and valuing collaborations, consulting relevant literatures, considering available resources (both available tools and monetary resources), valuing precision and accuracy, valuing scientific knowledge as evidence, being critical, creative and curious, and being interested and

engaged in scientific activities and processes. In calling these “scientific” ways of knowing, doing and being, I do not mean to imply that other disciplines do not also value some of these same things, or participate in similar ways of doing (i.e “being creative” is not solely the purview of science). Instead, these are a set of values and practices that are commonly associated with scientific work, even if they are not solely situated in a scientific domain. In the following, I highlight some of the most common ways that scientific practices appeared in the making of the climate change course. The later example from the Greenhouse Effect meeting addresses more of these, and in greater detail.

### 1. Collaborating

Science is understood to be a collaborative process (NRC, 2007, 2009; Latour, 1986), and the CGU scientists designed their development work in a collaborative way as well. One of the key characteristics of the high school climate course project was that it was set up with the goal of forming a partnership between scientists and teachers. Margaret and Lilian also recruited a large number of climate scientists-- both professors and graduate students— to participate at different points in the curriculum when they needed specific scientific or educational expertise. They also enrolled my help as an educational consultant, and had an educational evaluator assess their teacher professional development workshop and help create survey instruments for use in the classrooms to evaluate the developed activities.

Several times over the course of the project, Margaret commented on how she wanted the teachers to help the scientists with pedagogical design work. She encouraged teachers

to partner with graduate students designing specific activities, to provide support on the pedagogical design. As mentioned above, the very idea to have a more activity-focused class was the result of a conversation with a student. These collaborations allowed Margaret to participate more deeply in pedagogical ways of knowing, being and doing. For example, toward the end of the project, Margaret shared a pedagogical strategy a teacher had suggested about how to work with climate deniers in class:

1. **Margaret:** One of the teachers says when the students come in and say, wow, this is, you know, I believe [that climate change isn't happening] because of this, and she says: "Bring in the resources. Let's look at the resources together." So she puts it onto the students to talk about [the evidence]-- and they end up being, I think, more convinced in the long run.

One purpose of collaboration is to share knowledge and learn from others with specific expertise, and in the above quote Margaret describes how the expertise of the teachers has given her new insight into strategies for dealing with the challenging teaching situation of working with climate deniers.

The scientists also collaborated with each other, and shared responsibilities according to each other's varying scientific expertise. Because climate science is a large interdisciplinary topic, the scientists themselves vary in their disciplinary expertise. For example, individuals may specialize in particular curricular areas such as ocean heat transport, cloud behavior in models, or how rainfall affects the isotopic composition of organisms. In the graduate student recruitment process, graduate students were recruited

from a wide variety of disciplines. They were encouraged to develop an activity that fell within their area of scientific expertise, such that many of the different aspects of climate would be covered in the activity development process.

In addition to a variety of scientific expertise, the scientists also vary in their experiences with teaching particular topics. Thus, over the course of the project professors, graduate students, and recent graduates, all of whom had experience with teaching various components of climate science were consulted about their experiences and strategies. As they constructed the activities, they also collaborated with those outside of the project. For example, graduate student Clara reported asking help of her friends and lab-mates when writing up her lab. Thus, the collaborative way of being that is a standing practice for these scientists became an integral part of their course construction.

## 2. Contextualizing work in larger body of literature

Throughout the course construction process, the scientists sought to leverage existing literatures. Over the year, scientists consulted documents on education and searched for peer-reviewed literature on climate change education and communication. They referenced articles on science communication such as the Six Americas studies from the Yale Project on Climate Communication (Maibach, Roser-Renouf & Leiserowitz, 2009), articles about goals for climate change education (e.g. Sommerville, 2010) and conceptual understandings of climate concepts (e.g. Shepardson et al., 2010). They also leveraged the 2009 Climate Literacy standards (“Climate Literacy: The Essential Principles of Climate Sciences,” 2009) and the IPCC reports (IPCC, 2007a). In a workshop I facilitated on science teaching and learning, I brought in the NRC research consensus volumes and literature on

broadening participation in science (e.g. Banks et al., 2007; NRC, 2007; 2009). Grant also shared several articles on science epistemology that he gives to his college sophomores. In addition, the scientists actively searched for existing curricula, and articles on existing curricula. One such article (Lueddecke, Pinter & McManus, 2001) provided the impetus for the deconstruction of the CO<sub>2</sub> in a Bottle experiment and creation of the Greenhouse Effect demonstration that is the discussion of the example at the end of the chapter.

In addition, instead of constructing activities from scratch, the scientists searched online for examples of labs and lesson plans, and used other existing educational resources, such as the course textbook. Madeleine, in particular, relied heavily on the textbook to help her gauge the appropriateness of scientific content, and to help her structure the year-long curriculum arc. While these last examples are of resources that are not the standard peer-reviewed literatures that scientists might consult in their own research, I would argue that they serve a similar purpose in creating a baseline context and providing a template for work, similar to a scientific paper's methodology section.

### 3. Using scientific tools and technology

In the curriculum development process, use of scientific tools and technology was a recurring theme. In one of the first planning meetings to discuss learning goals, Margaret, Lilian and Grant established that having the students become familiar with scientific technology was a high priority for the course. This included having students use common computer programs like Microsoft Excel. Many of the activities developed thus used Excel, including a simple climate model written by Margaret, a graphing activity created by Clara that looked at trends in climatological data from weather stations, and an exploration of

data of past climate change created by Madeleine.

At least two graduate students also incorporated authentic scientific tools into their activity. Madeleine's activity exploring past climate involved the use of ice cores, and an understanding of how proxies are used as a tool in scientific investigations of past atmospheric compositions. Another team of graduate students created a series of activities using small temperature sensors called iButtons, a tool they use in their own research.

In addition to having technology and scientific tools be a focus of the course, the scientists also leveraged their own expertise with specific tools and technology during the development process. For example, in developing her activity, Clara had to access online repositories of weather station data, identify the appropriate data sources, download the data, process it using the mathematical program Matlab, and then export the data into Excel. This required technical knowledge on her part, in order to be able to use Matlab to do the processing, and familiarity with online scientific resources such as the weather station data. Because of Clara's depth of scientific knowledge and familiarity with these scientific tools, she was able to bring this practice into her educational work.

Using scientific tools and technology to support scientific practices is an important feature of science education as laid out in the *NRC Framework for K-12 Science Education* (NRC, 2011). Not only did the activities scientists constructed require expertise in scientific practices, they also were designed to help increase learners' expertise in scientific practices such as, in Clara's case, data analysis, and to increase proficiency in the use of technology to support these practices. Because of their expertise in scientific practices, scientists have the potential create learning opportunities for scientific practices that allow students access to authentic scientific work. Opportunities and challenges for scientists'

involvement in this work is discussed in more detail in Chapter 4 of this dissertation.

*Teaching and learning climate science across settings: The influence of past participation in educational settings*

Graduate students and faculty involved with the project come from a variety of backgrounds, with a range of previous experiences in both the sciences and education. In addition, the participants in this study ranged from first-year graduate students who had just arrived at the university when this study began, to advanced doctoral students who had been at NU for six or seven years, to tenured faculty members. These past experiences influenced how the participants chose to be involved in the curriculum development, what they valued and prioritized in the process, and what existing skills and resources they brought into their work.

1. Valuing authentic, problem-based learning

One area where the differing backgrounds of the participants, and the ways of knowing, doing and being afforded by these backgrounds, became apparent is in an analysis of why the scientists decided to include “hands-on activities” in their course, what “hands-on activities” meant to the different scientists and what was important about them, and what activities in particular the individual scientists decided to create. In interviews, and in conversations in the meetings and informal conversations, graduate students discussed that they not only valued hands-on activities, but that they specifically valued activities that were scientifically authentic and problem-based, and that this value came from previous experiences both as students and teachers in science classrooms.

Madeleine was a first year graduate student, who arrived at the university after five years of working as an educator on sailboats. She had worked in a variety of educational programs on sailboats, but told me that she felt one program in particular was by far the strongest because in addition to giving students the opportunity to go to sea, this program also allowed students to design and implement their own research projects. It was this research experience that distinguished this program from the others, and in the following exchange from our initial semi-structured interview, Madeleine discusses the program, what she sees as the benefits of that program, and how it differed from her own educational experience:

**1. Madeleine:** I think they're [the program] the only ones that actually do research at such a young age for kids. Like, all these other programs are like three hour stations and you kind of taste what's going on. But here they're actually thinking about what research is-- it's the only place that they're coming up with a question, they're coming up with a hypothesis, they're coming up-- then they're collecting data for three days and maybe it's only five data points, but they're doing deployments, to write down some value or some number, and then they don't leave it at that, you go back and you synthesize that data and try and see what it means. So it's the only program that has kids, like, doing that extra step.

**2. Elly:** So what do you see as the benefits of having the kids doing the extra step?

**3. Madeleine:** Well, it wasn't until I was in college that I even thought about what research is. So now I've been thinking about a really early age what research is, and I think that there's a lot of excitement into that, because you don't know the answer. Maybe you won't ever know the answer, but you can get a hint at it, and the goal of that program, [name's the program], is to get kids, more kids interested in science.

In her first turn, Madeleine discusses the difference between this program that has students “actually do research at such a young age for kids” and other programs where the experience is “three hour stations.” Madeleine values the fact that this educational program allows students to participate in many authentic scientific practices, such as “coming up with a question,” “coming up with a hypothesis” and having the opportunity to “synthesize that data and try and see what it means.” The approach Madeleine describes here parallels an approach to teaching “science in practice” that allows students to design and conduct empirical studies in educational environments (NRC, 2007; 2011). In response to my question about what benefits these further activities allow students, Madeleine explains that she feels that engaging in research can help spark student interest and engagement. She draws on her own experience as a student not being exposed to research until a much later age, and states that engaging in the research practices can help generate “a lot of excitement” because they spark learner’s curiosity to answer questions that “you don’t know the answer to.”

In this excerpt, Madeleine connects scientific ways of doing around scientific research practices to scientific ways of being— that is being curious about the natural

world and being excited and interested in science. Madeleine values these authentic scientific practices because of their potential to further students' trajectories into scientific ways of doing and being. In a professional development workshop for the graduate students we discussed what it meant for students to authentically participate in science. Madeleine told me that she liked the idea of students "acting like a scientist" and adopted this phrase to describe what she was trying to do in her ice core activity. She used it several times in presentations to and conversations with teachers and other graduate students, and included the phrase when describing the activity she would make in the proposal for her capstone project. Madeleine's perspective has similarities to those of discovery learning activities espoused by the Interaction Period of educational reform, as described by Linn, Songer & Eylon (1996). These were designed with the goal of giving students "experience engaging in scientific inquiry, both to understand the nature of inquiry and to gain enthusiasm for science learning" (p. 468). Negotiating student-driven inquiry with necessary guidance and scaffolds remains a focus of scientific instruction today.

Second-year graduate student Scott shares Madeleine's view that giving students the opportunity to engage with authentic data and practices will increase student excitement about science. Scott draws on his own experiences of feeling excited by seeing data patterns when thinking about designing an activity for students using atmospheric circulation data:

- 1. Scott:** You actually see the Hadley circulation with the data [that he is using in his activity] if you look at it right. I think that is sort of cool to make, like, tangible,

like you don't just-- you can draw it on the chalkboard and they sort of get the idea and they can rationalize it, but that it actually works in real data is cool...To simplify the process to where they can actually get involved in the science, that seemed like a good way to make kids excited about it. Cuz I think some people think climate models are cool and like models and that kind of stuff, and so if you make it to where they're think they're sort of interacting with the data on that scale, maybe they'll get excited about it.

Scott mentions two benefits of having students being able to actually manipulate data. The first is that it makes it more “tangible,” that is, it might aid conceptual learning. The second is the fact that seeing concepts play out in the data is something that Scott thinks is “cool,” and that might help students “get excited about” science. Here, Scott is drawing on his personal experience of excitement when finding patterns in data, and seeking to replicate that experience for students by creating opportunities for them to learn concepts through the manipulation of authentic scientific data.

Prior to starting graduate school, graduate student Michelle worked as a scientist for the government and has maintained an interest in both air quality science and policy. She has significant experience teaching, as a teaching assistant in graduate school and as an English as a Second Language teacher in Ecuador, and is the coordinator of her department’s outreach program. However, it is her own experience as a student, and an awareness of what best aids her own learning, that most influences her opinions about how to create projects. In our initial interview, Michelle told me that she “like[s] the idea of students doing research projects. I think my learning is always project based.” She

appreciates this kind of learning to such an extent that she actively seeks out courses that structure the curriculum around projects because she says “it expands my learning.” For Michelle, the value in these projects is less about generating interest and excitement, and more about retaining and deepening understandings of scientific processes and concepts. She compares two separate class experiences she’s had, one that was project-based and one that was not:

**1. Michelle:** I’m working on some regurgitation problems right now for this class that I’m taking where you just like look at this chart and move things up and down and I’ll forget it next week. But when you actually have to learn something through and through— like, I took a remote sensing course last quarter and we had to do a-- we had to take like level one data, which is data that nobody uses and-- from a satellite-- and we had to like retrieve something from it. So we had to write all this code to pull out some information. Yeah, and so, like, I had to really learn the process. I had to learn how it was done in the real world...And you just think about it all the time, and like working, and thinking and all of that. That’s what I like about projects, that you get to-- you really get to get in there and you remember everything you’ve done because you’ve thought about it so much.

Unlike the “regurgitation problems” that Michelle was working on when we spoke, Michelle indicates that she had success learning in the remote sensing course which had students learn something “through and through” and “really learn the process.” She notes that that the project— transforming messy data into useable data— was what “was done in

the real world” and that this project helped her “remember everything you’ve done because you’ve thought about it so much.” This “real world” project helped Michelle learn and retain not only *conceptual* understandings, but also understanding of *processes*, the important social and material practices of the scientific community. Thus, these classes were bringing her not only into scientific ways of knowing, but also ways of doing.

Clara, a graduate student creating a lab around finding trends in climatological data in Excel, makes a similar connection between scientific ways of knowing and doing. For Clara, figuring out how to write the lab in a way that made the students engage with and think about the material was challenging. In our initial interview, Clara talked about the challenges of getting students to engage deeply in a lab:

**1. Clara:** Um, I think always the problem is, when you have these labs, is that they're in small amounts of time and there're steps A, B and C. And people like march through steps A, B and C and they get the answer and they never really think about what they're doing, or what-- you know, it is easy to do a lab without ever thinking about it, you know?

Clara is critical of activities that students can complete without having to deeply reflect on and wrestle with the material- due to their structure (i.e. “Steps A, B and C” that “people like march through”) or due to the “small amounts of time” available in a class period, a criticism that echoes critiques of the “cookbook lab” instruction model of science education (NRC, 2005). Like Michelle, she values with a long-term, deep engagement in the authentic activities. Clara didn’t have previous experience in creating curriculum and had

little experience as an educator, though she had tutored in the past. In her reflections on the curriculum development process, she reported struggling to create a lab that would be successful in engaging students the way Michelle's remote sensing experience engaged Michelle. Like Michelle, she values experiences for students that bring them into a more authentic way of doing science than just "steps A, B and C" that leads to a deeper scientific way knowing.

Given the prevalence of the top-down lecture model of science teaching, it might be expected that the CCG graduate students would have valued or gravitated toward this model when designing their activities. However, as seen in the above analysis, the graduate students had a wealth of prior experiences from their work as teachers, students and scientists that informed their design process, and led them to value experiences for students that were authentic to the scientific practices. However, Madeleine, Michelle, Scott and Clara had diverse reasons for valuing these experiences, including the belief that they increased student excitement and engagement, deepened conceptual understandings of scientific knowledge and processes, and increased retention of information.

## 2. Using personal experience as evidence in argumentation

In addition to bringing with them arguments for particular pedagogical styles (i.e. authentic, problem-based instruction), the scientists in this study also drew from their own experiences as educators in both formal (e.g. teaching a college-level course) and informal (e.g. dinner table discussions about climate change with extended family members) settings when thinking about the conceptual understandings that they wished to promote through their course. Throughout the process of creating the curriculum, scientists shared

their own experiences with teaching the material and the challenges that arose, and argued for various approaches to structuring course content. This practice is similar to that seen in their scientific work in which they collaboratively make sense of phenomena, but the evidence used to support the arguments in this case have a different character than the evidence used in other settings. For example, in scientific processes, scientists drew on accepted scientific knowledge, peer reviewed literature, and data from repeatable experiments for evidence. When discussing conceptual understandings or pedagogical techniques, the evidence included a greater amount of personal experience, and few to no allusions to peer-reviewed literature, experimental results or a greater body of knowledge. Often scientists would relate activities that they had tried with their own college classes, and the results of these various activities. For example, in a meeting to discuss performance expectations, Jerry, a professor, would often comment on things he had done with students in his class:

**1. Jim:** Well, what we can do is very simple calculation of the CO<sub>2</sub> lifetime in the atmosphere. Which can be very powerful for them [students] to realize that, oh, I took what I knew and I calculated how big of a problem this actually is.

Here, Jim describes a calculation that he had his college students do, which was to use a simple model to calculate how long carbon dioxide stays in the atmosphere. He claims that this calculation “can be very powerful” for his students because they are able to calculate for themselves the severity of adding excess carbon dioxide to the atmosphere. Margaret then clarifies that the calculation is done based on the “sources and sinks” of carbon

dioxide, which Jim confirms. Jim makes the argument that this is “very powerful” for students. While he does not provide explicit evidence for this claim, he is most likely implicitly drawing on some experience in his classroom that led him to infer that not only was the calculation powerful, but it was powerful because the students were able to calculate the severity of the problem using their own knowledge of sources and sinks. This practice of arguing based on anecdotal evidence was common as the scientists discussed classroom pedagogy and conceptual difficulties for students. While this was the most common mode of argumentation seen in discussing the curriculum development, it was uncommon (though not absent) in scientists’ arguments about scientific knowledge and practices.

### 3. Considering differences between scientific and other ways of knowing

Throughout the course of the development project, scientists multiple times commented on the difference between their ways of seeing the world, and those of people who are not so deeply involved in climate science. Scientists were cognizant of differences between their own ways of knowing and understanding scientific knowledge, and that of students and teachers. The following is an excerpt from a meeting in which a variety of graduate students and professors who had previously taught the college Atmospheric Sciences course were brought together to define performance expectations for the high school students. The conversation turned to how isotopes of carbon can be used to show that humans are responsible for warming. In the following, graduate student David shares an experience he had in which he noted a discrepancy between his own experiences of understanding a graph and that of his students that he had had while working as a teaching

assistant (TA) for Jim. Robert, another professor, then introduces the idea that many of the students come to these classes with outside knowledge that contradicts the scientific content of the course:

1. **David:** I remember when I TA-ed for Jim and we did the “How we know it's [climate change is] from humans?” I remember we like put a plot up there, and we were like up in front and like: “Wow, it's so cool, it's so beautiful!” *((laughter))* and the students were like try-- trying to understand how beautiful this plot is *((laughter))*.
2. **Robert:** *((Quickly, and in a voice indicating that he is speaking as a student))* My uncle says that, you know: “Volcanoes are a hundred times more than all of man's emissions.”
3. **Jim:** Yeah.
4. **Grant:** Right, right.
5. **Jim:** Integrated over geological time. *((laughs))*

David begins by relating an experience that he had as a teaching assistant for Jim. David says that he and Jim showed a plot to their students, which David and Jim both found to be compelling and valued highly. This graph supported the argument that climate change is human-influenced. However, David notes that the students had a different response to the plot than he did. They weren't able to immediately see “how beautiful” the plot was, but instead struggled to understand it. David and Jim's experience in climate science has afforded them a different way of knowing than the students and in turn

influenced their values and ways of being. They not only can interpret this graph quickly (i.e. reading these kinds of graphs is habit for them), but they also see a deep value in it. In this instance, scientists recognize this “expert blind spot,” i.e. that their deep expertise in this scientific practice makes it difficult for them to anticipate challenges for learners (Nathan, Koedinger & Alibali, 2000). Thus there is a difference between their ways of knowing and being and that of the students, who they are trying to support in developing these ways of knowing and being, a phenomenon discussed in greater detail in Chapter 4 of this dissertation.

After David’s turn, professors Robert, Jim and Grant bring up some of the arguments that they often hear *against* anthropogenic climate change. These are similar to those discussed in Chapter 2 of this dissertation. Robert shares an example of the type of argument that he commonly hears from his students— that climate change is not anthropogenic because “my uncle says” that volcanic emissions are more important. In introducing this argument, Robert is highlighting two important differences between the climate scientist’s ways of knowing and that of this hypothetical student. The first is the source of the evidence— by using “my uncle says” Robert is indicating that the source of the information is suspect, i.e. that the student is drawing on evidence that has not gone through a rigorous scientific construction process. Robert’s example makes sense given that polling research has shown that climate deniers are more likely to trust friends and family than scientists as sources of information (Leiserowitz & Smith, 2010). The second difference is that the volcanic emissions argument is an example of taking scientific knowledge out of their proper context, that is using scientific knowledge as evidence in inappropriate ways. In this case, Jim points out the flaw in taking volcanic evidence out of

context— that while it's true that volcanic emissions are greater than human emissions, that is only true if it is "integrated over geologic time," that is, if you are looking at *all* volcanic emissions in the history of earth, not just the ones that could potentially be contributing to current warming. Grant's turn of "Right, right," indicates that this is a kind of argument that is very familiar to the group. This short excerpt gives an example of how the scientists recognized differences between their ways of knowing and that of their students, and indicates that these differences are very common occurrences that are familiar to the scientists.

The scientists also discussed how they have adapted their own teaching to be more in tune to the ways of knowing of their students. In the following excerpt from the same meeting, the scientists are discussing a number list of learning goals for the class. Grant stops as he is reading the list of learning goals to relate his own experiences as a teacher, and how he has noticed a difference between the types of evidence he finds convincing and the types of evidence that the students find convincing. This leads to a discussion about why these differences exist:

- 1. Grant:** Number nine is the observation of current temperature trends, um, and I've tended in my own class to put emphasis on the surface temperature record. I'm becoming more convinced that-- many people who aren't scientists respond much better to the non-temperature record indications of temperature change interestingly enough to me, they, um, they seem much more convinced by telling them that people have been observing changes in when the plants flower in their garden and when

the birds show up then things like that, and showing them the temperature record. Which I find fascinating.

- 2. Jim:** //That's interesting.
- 3. Grant:** I really see that.
- 4. Jim:** It's the two degrees. They just don't-- they, they live in these twenty degree swings and they think two degrees is nothing.
- 5. Robert:** *((speaking quickly, in a voice indicating he's a student))* And my flowers are opening earlier! The robins are coming sooner.
- 6. David:** Or it was cold last winter.
- 7. Elly:** Well, and changes in flowers and plants and birds and things, those are things they may have experience with themselves.
- 8. Grant:** I think that's it.
- 9. Elly:** Yeah.
- 10. Grant:** I think Jim's probably right. It's the fact that-- I look at a one, one and a half degree temperature change and I think that's a big deal, and they think it's nothing. And it's all in the way you view the world.
- 11. Robert:** Because they're not calibrated to the ice-age temperature change.
- 12. Grant:** Right. But if you tell them that birds are showing up two weeks earlier or the frost-free season has extended by a month, by two weeks on either end, you know those are things that, that seem to resonate much, much better with a lot of people so I've tended to put-- maybe push more of that, um.

Grant begins by saying that he's seen "people who aren't scientists" be more engaged by indications of warming that go beyond the "temperature record" (a graph of how temperature changes over time). Jim posits that the reason for this is tied to the fact that the temperature record only shows a 2 degree increase, which may seem negligible next to the student's experience of living in a highly variable climate (the "twenty degree [temperature] swings"). Robert and I both comment on the fact that other kinds of evidence, such as changes in the life cycles of flowers and birds, may be things that students *do* have direct experience with. Grant agrees, and also agrees with Jim. Notably Grant attributes this difference to being "all in the way you view the world." Thus, Grant is indicating that there is a difference between the scientist's way of being in the world and a non-scientist's way of being in the world. A scientist's way of being includes valuing of temperature records and a particular way of understanding and placing importance on a 2 degree temperature shift. A non-scientist's way of being includes valuing non-temperature forms of evidence, and placing less importance on a temperature shift that is within the normal bounds they feel in their everyday life.

Robert indicates that this difference has to do with not being "calibrated to the ice-age temperature change." That is, someone who is "calibrated" would understand that a two degree temperature variation was actually significant when compared to past changes. Someone who does not have that same understanding of cyclical temperature changes throughout earth's history, would not find the two degree difference as compelling. This "calibration" is, in Robert's understanding, one of the climate scientists' ways of being, and has been described in the research on expertise as differences in how experts and novices notice meaningful patterns of information (Bransford et al., 2000).

Grant notes that these differences in ways of being and knowing, has caused him to change his pedagogical approach to include multiple types of evidence in his class. Thus, scientist's past participation in educational work influences their understanding of pedagogy, and their current participation in the construction of the course.

*Example: Applying Scientific Practices and Process to the Construction of a Greenhouse Effect Demonstration*

During the creation of the course, the scientists became engaged in problem-solving the development of a demonstration of the Greenhouse Effect (GHE)<sup>11</sup>. During this process, the scientists brought many of their existing scientific practices into this new mode of participation in curriculum development, and also leveraged past experiences teaching GHE-related concepts. In this worked example, I examine the ways of knowing, doing and being that scientists leveraged during a meeting they held to discuss the revision of a GHE demonstration. In the first half of this meeting, the process of developing a GHE demonstration took on many of the characteristics of scientific inquiry processes that they employ in their research. In this part of the meetings, scientific practices such as

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<sup>11</sup> The Greenhouse Effect refers to the absorption and re-radiation of energy (heat) by particular atmospheric gases known as Greenhouse Gases (GHGs). The Earth receives energy from the sun in the form of both longwave and shortwave radiation (i.e. radiation with short wavelengths, like visible light, and long wavelengths, like infrared radiation). Some of this energy is reflected into space by the atmosphere and Earth. The Earth also emits energy in the form of longwave radiation. This longwave radiation can be absorbed by GHGs like carbon dioxide and water vapor in the atmosphere and re-radiated, heating the Earth.

As shorthand, scientists may refer to the incoming solar radiation as shortwave radiation and the outgoing radiation as longwave radiation. This distinction between longwave and shortwave radiation becomes important when making a GHE demonstration, because it is the *longwave* radiation that is involved in the GHE. However, this infrared radiation is invisible, which poses pedagogical challenges.

constructing scientific questions and hypotheses, collecting and analyzing data, modeling, and arguing based off of scientific evidence were at the forefront. In addition, the scientists engaged in critical questioning of each other's activities and had a high level of collaboration, two habits associated with their scientific work. In the second half of the meeting, however, there is a shift to practices and problem-solving more consistent with pedagogical ways of knowing, doing and being, including identifying and isolating concepts of interest, speculating on possible student learning trajectories and considering classroom pragmatics.

The GHE is an essential concept for understanding the climate system, but is notoriously difficult to demonstrate in a laboratory or classroom setting. In addition, research has shown that establishing a conceptual understanding of the GHE using current models is problematic (Shepardson et al., 2010). The meeting in this example arose because the CCG scientists had been talking about trying to adapt a common GHE demonstration called CO<sub>2</sub> in a Bottle to their needs (the CO<sub>2</sub> in a Bottle experiment is described in Lueddecke, Pinter & McManus, 2001). However, the scientists had concerns from the beginning that the CO<sub>2</sub> in a Bottle demonstration did not accurately represent the GHE, i.e. it worked for the wrong reasons. What followed was a period of GHE demonstration development, during which the scientists employed many of the techniques and processes of science to frame and explore problems, including iterative work of devising problem statements and questions, setting up experiments, collecting and analyzing data, collaborating, and building on established research literature. After they had satisfied themselves that the demonstration did not work for the correct reasons, they then expanded their ways of being, knowing and doing to include those more closely

associated with pedagogy. What follows is a chronological description of the GHE, and an accounting of the scientist's work to transform the concept into an engaging, classroom-appropriate activity, that highlights how scientists draw on ways of knowing, doing and being scientists' bring from their scientific and educational experiences in an iterative, non-linear fashion.

Before the meeting began, Lilian and Will, her undergraduate assistant, had set up the CO<sub>2</sub> in a bottle experiment. In this experiment, two large jars were heated with heat lamps, as shown in Figure 1. In one jar, Will mixed baking soda with vinegar, a reaction that produces CO<sub>2</sub>. The theory behind the CO<sub>2</sub> in a Bottle experiment is that the CO<sub>2</sub> will absorb and emit more infrared radiation from the heat lamp, leading to an increase in temperature in the jar in which the reaction took place. Throughout the meeting, Will recorded the temperatures of the two jars. Grant, a professor, initially questions Will and Lilian closely about exactly how they had set the experiment up, and how they had controlled for various variables in the experiment. After a few minutes of this, Grant explained his concern:

1. **Grant:** I'm not trying to be difficult. You know, trying to understand what's going on here requires-- this is not as obvious as you think. And what people are telling you, I don't think is-- the stuff that-- this is supposed to show you CO<sub>2</sub> absorption, I think it's wrong. I don't know what's going on yet, but I'm pretty convinced it's not CO<sub>2</sub>-generation that makes this.



Figure 1 Experimental Set-up for CO<sub>2</sub> in a Bottle. Two vases were heated by heat lamps. Both contained water and a digital thermometer. Baking soda was added to the water in one vase (in foreground) to generate CO<sub>2</sub> and both were covered with plastic.

In this initial exchange about the parameters of the experiment, Grant sets the priority for the beginning of the meeting, which is to uncover what exactly is “going on” in the experiment. He asks the critical questions about the experimental set-up to gain insight into “what’s going on” inside the bottle. He then makes an assertion that “it’s not CO<sub>2</sub> generation that makes this,” i.e. Grant doesn’t believe that it is the excess CO<sub>2</sub> in the experimental jar that would lead to an increase in temperature. In this beginning section of the meeting, Grant, Lilian and Will established the focus of the scientific investigation: What is going on with the CO<sub>2</sub> inside the bottle? After Grant makes this initial statement

that CO<sub>2</sub> is not responsible for the temperature increase, he then continues to ask critical questions about the experimental set up. He then is able to construct an initial argument for why he thinks that CO<sub>2</sub> generation is not responsible for any temperature increase in the bottles:

**1. Grant:** I think it's highly suspect because if I think about the radiative transfer that's going on inside these two jars, I don't see any way that the radiative transfer can explain what's happening. The analogy people are making are if those jars were sitting outside is simply not correct. They are not sitting outside; they're sitting in a room in which, if you had a directional IR sensor...then you would see the same radiation no matter where you pointed it. Alright? So there's no loss of radiation from a window or even what's going on out there in the real world. So, the idea that you've changed the absorption column inside that little jar and inside from that little jar and that's driving the change in surface radiation and therefore-- I think is bogus.

Here, Grant provides evidence for his argument that CO<sub>2</sub> generation is not responsible for any observed increase in temperature using the existent body of scientific knowledge around radiative transfer. He argues, using this scientific evidence, that unlike what the “people” say (in this case, he is referring to the people who wrote up this demonstration), the radiative properties of the room do not allow for a change in the absorption of radiation within the jar (that “you’ve changed the absorption column inside that little jar”) to be the responsible causal factor for a temperature increase. He expresses this new argument in colloquial terms— that this assumption is bogus, and has supported it with his expert

knowledge of radiative transfer.

After Grant makes this assertion, a second professor, Keith, makes another argument. Keith argues that in addition to the problems with the radiative transfer, a second problem is that the glass absorbs a significant amount of the relevant IR. Because of this, he makes an argument that: “I would go out and say there's basically no infrared light getting into that jar.” This leads to a lengthy discussion of what exactly is happening in the jars.

In order to answer the question of “what’s going on” in the jars, the scientists employ a number of methods, including abstract modeling and drawing on data from past and current experiments. They use evidence from these models and experiments, in addition to evidence drawn from peer-reviewed scientific literature to convince themselves that CO<sub>2</sub> is not, in fact, responsible for the change in temperature.

After some discussion, Keith offers an alternative explanation to what might be happening in the jars besides radiative transfer, saying “I suspect the majority of it’s convection,” and Grant agrees, saying: “I think it’s right. I think it’s convection and conduction; I don’t think it has anything to do with radiative transfer.” Grant then goes to the whiteboard, and constructs a schematic. This schematic is a scientific model of the relevant radiative processes in the jar, and includes illustrations of both jars, arrows indicating the various IR sources. He and Keith then construct a series of equations that describe these processes. Though this is a collaborative process, and the tone is very collegial, there is a lot of disagreement and arguing about how to best set up these equations. Both scientists support their assertions with evidence, often using short-hand to reference things with which they would both be familiar. In the representative excerpt below, Grant and Keith discuss the appropriate value for the emissivity (how much

radiation can be emitted by a substance) of the glass jar, and then come to an agreement about why the IR from the heat lamp is negligible. Notably, despite the fact that this meeting is ostensibly to discuss the creation of a pedagogical tool, this exchange bears more resemblance to a scientific inquiry process than standard curriculum development. The model Grant draws on the board are shown in Figure 2.

- 1. Grant:** OK, so let's do this in the abstract. Alright? So here's the radiation that's coming down from above (*draws on board*). Alright? And we're going to call-- this is, this is the blackbody radiation from the earth, and now we have...probably need to do this spectrally, but let's not worry about that. Alright? So now you have radiation from the jar, now you have the surface down here. Now this is-- this stuff isn't in equilibrium because this thing's going to remain unchanged-- it's too large to respond. So what, what the surface sees is...the emissivity-- this is cheating a little bit.
- 2. Keith:** Let the emissivity be one. Right, I mean make it as simple as possible.
- 3. Grant:** Well, emissivity-- so if the emissivity of everything is one, then how do you get anything to change? If it's already one, then you can't change anything because all of this energy is already absorbed.
- 4. Keith:** Well, the way I'm thinking about is you've got two time steps, right, you've got one where you don't have any CO<sub>2</sub> in that box and another where you do.
- 5. Grant:** Right, but the emissivity of this air mass is one.
- 6. Keith:** No it isn't. It's going to be zero initially. Right when it's--

- 7. Grant:** But it's not! It's not! Because we've got water vapor.
- 8. Keith:** Yeah, ok. Right-- I was trying to avoid -- I(h):i was trying to make it-- be one if you like. Yes. That's a huge problem.
- 9. Grant:** So there's gotta be some emissivity--
- 10. Keith:** Yeah, yeah, ok, all I'm saying is it changes, right? The radiation.
- 11. Grant:** //So then radiation from out of the surface is the emissivity of whatever's in the jar
- 12. Keith:** //Yes, OK.
- 13. Grant:** Times sigma-T-r to the fourth. Right, plus one minus that emissivity of the jar, times sigma-T-r to the fourth. Yeah, this is cheating because this is grey emissivity and the world's not grey and all that stuff. Um... but if, if I then-- alright, so if I were able to heat this up. Alright? Then what I would see is I have some new-- so I add some CO<sub>2</sub> right, I can write epsilon prime is greater than epsilon, right? Because I added CO<sub>2</sub>, but the-- it's not clear what these values are, but it's not like one is zero.
- 14. Keith:** Right, right, yeah.
- 15. Grant:** It's point seven-five or point 8 or whatever. I don't know
- 16. Keith:** Point seven five oh oh.
- 17. Grant:** So you're going to get something that looks like THIS now. Alright, so the change that you're producing is, is not, it's not this alone, there's this compensating part-- there's this little bit of change that you're finding that you've added a little bit of emissivity here but you subtract off a little bit here. So it's not like you get the full change here because you

reduced this, so the net energy, the change you can get is going to be less than what you think. It's not very big. It's not the same as calculating what the column would be.

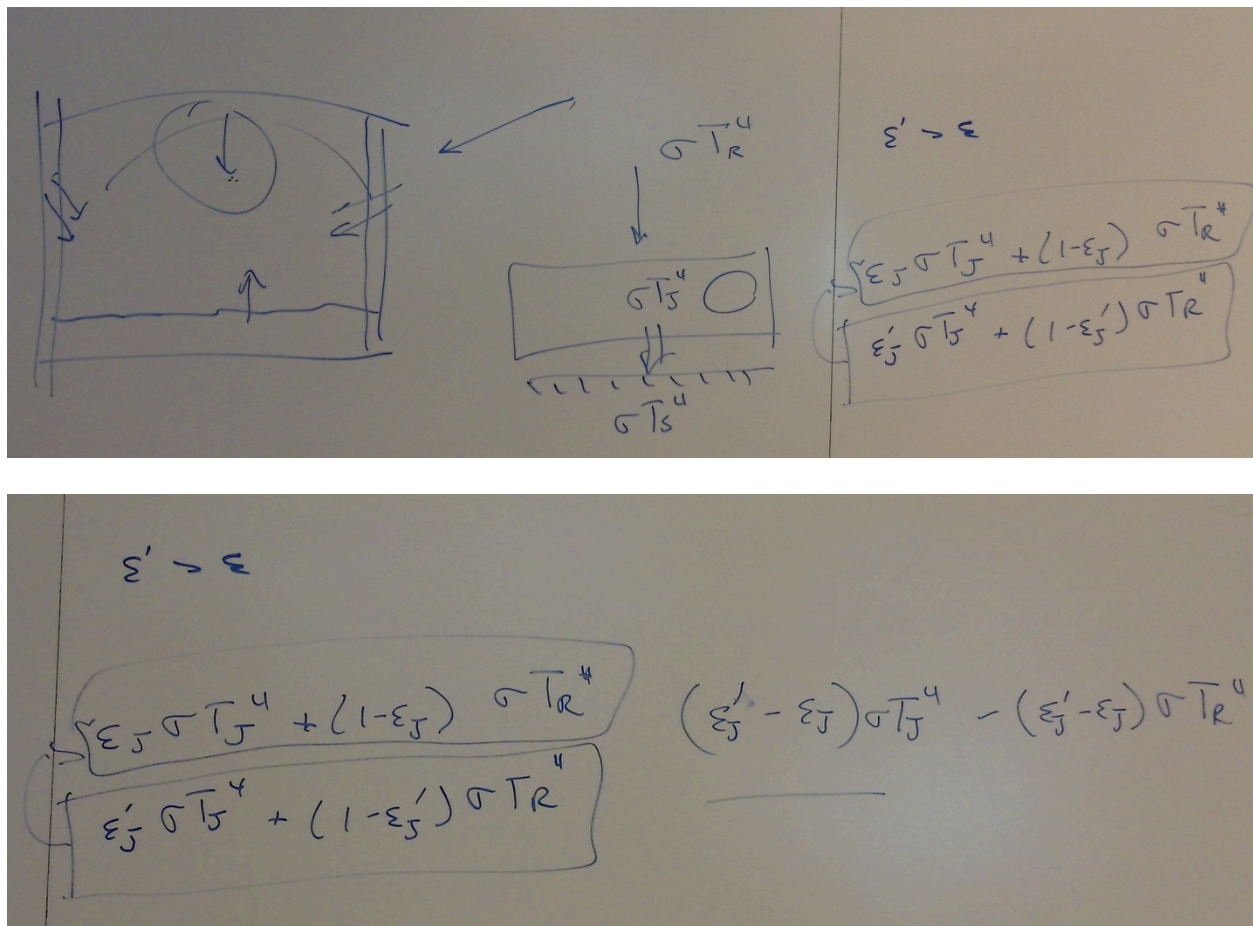


Figure 3 Figures and equations that model CO<sub>2</sub> in a Bottle system

This excerpt and the models shown in Figure 2 demonstrate how Grant and Keith constructed their argument about what was happening inside the vases. Their initial disagreement is about the correct value of the emissivity of the jar. Keith initially wants to simplify the problem by ignoring water vapor, but Grant makes an argument for why that

would not be accurate enough. This negotiation is characteristic of scientists' use of conceptual models. In modeling, the representations are necessarily simplified or backgrounded while others are foregrounded, and all models are limited by certain assumptions and approximations (NRC, 2011). In this exchange, Keith and Jim are negotiating which approximations and assumptions are allowable in the given model. Once Keith agrees not to make this assumption, they agree on the results of this modeled system — that “the change [in temperature] you can get [when heating the jar with a heat lamp] is going to be less than you think. It's not very big.” This model is the first piece of evidence in support of the argument that the demonstration isn't working for the right reasons (because the change in IR absorption in the jar due to the radiative properties “is going to be less than you think”).

In addition to this argument using the modeled processes, Grant and Keith also draw on scientific technology and experimentation. During the meeting, they periodically check in with the ongoing experiment Will is conducting and discover that the temperatures in the jars aren't increasing in the way expected if the GHE is responsible. Instead, the experimental jar is colder, a fact that the scientists attribute to the fact that the vinegar-baking soda reaction is endothermic, or absorbs energy, lowering the temperature.

The scientists also used scientific technology that they were familiar with and had access to generate further evidence. Graduate student Michele brought an IR thermometer gun (a sensor that can remotely read an IR temperature) to the meeting, and she and fellow graduate student Madeleine experimented with testing the IR temperature of the room. After some discussion about whether or not the temperature guns were properly calibrated, Grant directed the students to take temperature readings of different areas of

the classroom. These led to consistent temperature readings (with one anomaly of the door, noticed by Madeleine). Grant ties this result to his previous argument about the radiative properties of the room:

1. **Grant:** I want the one in your hand pointing at the ceiling is the same as the board.
2. **Michelle:** Yes it is. It is.
3. **Grant:** Alright, now point it at the floor. *((Madeleine and Michelle aim their IR guns at the floor))*
4. **Michelle:** Yeah, yeah.
5. **Madeleine:** The door's cold.
6. **Michelle:** Yeah, we're-- they're-- they're consistent.
7. **Grant:** That's the point. You're in this huge warm bath of radiation. So the whole idea that you could block escaping radiation to space inside of a closed room is ridiculous. It's just not going to happen. This whole room is in an infrared trap in which everything's coming at the same temperature. So, even if I change the column, again I'm only changing it by-- those temperatures are about two degrees different. There's hardly enough energy to even possibly drive a temperature change at the surface. Because you're not starting with a differential.

The scientists demonstrate that the IR temperature within the room was consistent and that this supported Grant's previous argument that any change that they could make to the

atmosphere within the room would not be big enough to explain that observed temperature increase. This investigation with the temperature guns occurred almost half an hour into the meeting. At this point, the scientists switch directions from attempting to explain the processes of the jars to examining how to make a more effective demonstration. Though it was not explicitly stated, it can be inferred that at this point the scientists felt that they had provided enough evidence in support of their initial hypothesis— that the GHE explanation for temperature changes in the CO<sub>2</sub> in a bottle experiment was “bogus”— that they abandoned the CO<sub>2</sub> in a Bottle demonstration in favor of development of creating something new.

At this point, Michelle leads the meeting in a new direction, by refocusing the group on the concepts that the scientists are attempting to teach. Drawing on a conversation she had previously had with the atmospheric sciences outreach group, she suggests developing two demonstrations, each that teach a single concept that is relevant to understanding the GHE:

- 1. Michelle:** Can I present an idea that the atmospheric sciences outreach small subset group talked about-- I want to present an idea that the atmospheric sciences outreach talked about. You *((to Grant))* were actually there for this conversation, but it's been like a year and we haven't done anything with it yet.
- 2. Grant:** And I can't remember what we were talking about.
- 3. Michelle:** Perfect. Well just say you agreed with us. OK *((laughter))* Um, so we had talked about the same thing and gone the same way this

conversation is going, so it's circling, circling, circling and we're saying, you know, we can do this [the CO<sub>2</sub> in a Bottle activity], but we're not sure what this is showing. But we thought, you know, there's two concepts here that you're trying to teach and is it possible - you know, it would be cool if this worked and exactly the concept that you wanted to teach, but let's say that that's not possible, right. Let's say we can't come to that, that conclusion. Would it be possible to split it into two different concepts. So the first concept you're trying to teach is radiative transfer. How light interacts with clouds and the surface and things like that. And the oth-- the second concept that you're trying to teach is different gasses absorb different amounts of radiation and so let's leave the second one to be for the time being.

Michelle's suggestion is notable because it introduces a different kind of thinking than had previously been in play at the meeting. Instead of aiming to establish a scientific understanding of a the CO<sub>2</sub> in a Bottle demo, Michelle is directing the scientist's to think instead about the important concepts involved understanding about the GHE itself, not the GHE demonstration. Michelle suggests a technique of breaking down the complex GHE (which has so far been problematic to demonstrate) into two simpler concepts. After some discussion, Michelle shares an experience from her own teaching:

**Michelle:** We do the really simple experiment in the 101 classes where we have

the black square and the white square and we have a, um, like a burner as an infrared source and then we have one of those lamps as a, as a visible source, and if you, if you do the experiment first with one of the sources, um, they'll heat differently. Like the black and the white will heat differently, so I mean you can do that, and we use these to measure the difference between them.

After this, the scientists continue to discuss how to teach these concepts. As part of this process, they speculate on the aspects of the concepts that are likely difficult for students. One of these is the difference between heating by radiation and heating by convection and conduction. Grant uses the example of heat from a campfire to describe the difference between these two types of heating, and former graduate student Heidi suggests using a clear barrier as a pedagogical technique to enforce the difference between infrared and visual radiation.

**1. Grant:** The example I often use for that is campfires. That when, when you're sitting at the campfire and you're facing the campfire the side that's facing the campfire is nice and warm, but the side that's facing away is not nice and warm, and it's not because you've changed the temperature of the air between you and the fire. It's because that radiation from the fire is reaching you. And people sit up and they think about sitting outside and oh yeah, that air is not actually warm. And you can actually say if you really want to prove it, take something and so, so you're sitting there and you're feeling this radiation and well it's heating the air, well now

suddenly put something between you, a piece of cardboard or something like that between your face and fire and all of a sudden you don't feel that warmth anymore it's clearly not the air.

**2. Heidi:** Or better yet glass, because I mean something visually to get the visual versus IR difference.

Here, Grant shares from his own teaching practice. He describes his own experience with finding the campfire to be an effective model for explaining radiation— that is, that a campfire heats you not because it has heated the air, but because it is emitting infrared radiation which is warm. Heidi's suggestion to use a clear boundary instead of a cardboard one continues the process of developing a new demonstration. Grant further explains that this kind of experiment is important because radiation is a problematic concept for students:

**1. Grant:** See that might be the start of an experiment that-- because this whole concept of infra-- one of the things that I run into is people intuitively understand that if I change solar radiation the place should-- you know if I say if I increase solar radiation what going to happen to surface temperature, they'll go: "Well it's going to go up." If I say, if we increase infrared radiation in the atmosphere what's going to happen to surface temperature they'll go: "I don't know." I go, wait! Energy's energy. That concept is much more difficult. So that's not a bad-- this would be a positive thing if you could convince people that what they're feeling from the, sensing from these hot objects is actually radiation and not a warming gas.

At this point, the scientists have shifted from prioritizing understanding the specific scientific phenomena associated with a previously established demonstration, to identifying the relevant concepts and identifying areas that might be challenging for students. This was not, however, a clear modal shift from “scientific process” to “pedagogical process.” That is, the pedagogical focus *expanded* the set of practices on the table, it did not *replace* them. It is worth noting, however, the unlike the structured scientific inquiry processes used, the pedagogical processes remain less developed. That is, the scientists do not formalize a way to understand student learning in the same way that they have formalized their scientific understanding of the GHG demo. Their inquiry into the conceptual understandings of the students is less systematic than their inquiry into the climate science phenomena.

In the last section of the meeting, the scientists used their available scientific tools to begin to actively construct a new demonstration. In this section, they non-linearly iterated through scientific evidence, speculation on potential pedagogical strategy, experimentation and data collection, and arguing based off of scientific evidence. For example, in the following excerpt, Heidi finds a plastic bag in her backpack and she and Keith test the hypothesis that putting the plastic bag in front of the heat lamp will cause the IR temperature read by the temperature gun Keith has to decrease. The scientists test different plastic materials’ absorption of IR. In this case, the plastic is a proxy for greenhouse gases that are similarly absorbent in the IR.

**1. Keith:** Cuz that [plastic] will absorb in the visible. It's really nice to use

things that are clear in the visible so that they think about-- ok visible's going through just like with glass.

- 2. Michelle:** So plexiglass and plastic bag and—
- 3. Grant:** I wonder what teflon would do.
- 4. Will:** Yeah, you could use different types for plastics.
- 5. Grant:** *((Heidi pulls out a plastic bag from backpack, and brings it over to the heat lamp from the CO<sub>2</sub> in a Bottle experiment))* Aha! Aha!  
She's got a plastic bag.
- 6. Keith:** Oh and actually, speaking of plastic bags, a black plastic bag that's thin, like a garbage bag, is quite transparent to infrared, and so that's -- you could actually show that even though you can't
- 7. Grant:** //Where's your little— ? *((looks for the temperature gun))*
- 8. Keith:** Can't see through it, the light, infrared is still coming through.
- 9. Grant:** Shine your light [thermometer gun].
- 10. Keith:** Oh right oh right.
- 11. Grant:** Got it on the light [heat lamp]?
- 12. Keith:** It's hard to tell cuz my eyes hurt. *((laughter. Reads the IR gun))*  
55.
- 13. Grant:** So we have two of these?
- 14. Keith:** Yeah, I mean it'll take a little while to warm up.
- 15. Grant:** Got another plastic bag in there?
- 16. Madeleine:** *((offering Heidi a binder separator))* Here's a different kind of plastic.

- 17. Grant:** That's cool.
- 18. Keith:** Lay it on me. This is actually what I was saying...
- 19. Madeleine:** Oh, here's a plastic thing. *((Puts plastic bag in front of the heat lamp))*
- 20. Grant:** Alright, so this one's 55, you said?
- 21. Keith:** Yeah.
- 22. Grant:** *((looking at the plastic bag))* This' still got water in it. Somebody put water in it.
- 23. Keith:** Yeah, that helps. *((Takes a measurement with the IR gun))* 41!

The scientists' hypothesis that the plastic bag will absorb IR is supported when the initial temperature registered by the gun (55) decreases when Heidi puts the plastic bag in front of the lamp (to 41). Keith makes several comments that connect this experiment to how it would be used in a classroom. He talks about the value of using both clear and black plastics so that students will think about the differences between visible and IR radiation. He also connects the results of this experiment to the greenhouse effect in the last part of this excerpt in his last speech. The plastic bag that they are using has some water in it, and Keith comments that "that helps." That is, that the bag is absorbing more IR because it has water (an IR absorber) in it.

By the end of the meeting, the scientists had drawn on both scientific and pedagogical ways of knowing, doing and being to propose a possible avenue to pursue in their demonstration development. This process mirrored the knowledge construction processes of this scientific community, in that it was a social, open collaboration that required the

distributed expertise of individuals in multiple fields. This investigation into the science of CO<sub>2</sub> in a Bottle was dynamic, in that the scientists collectively pursued scientific explanations for observed phenomena via multiple methods, including modeling and experimentation. The discoveries made and explanations generated during this meeting served to open new avenues of inquiry that the scientists later pursued.

In a follow-up meeting, Michelle, Grant and I further tested the proposed set up. Though we finally decided that the demonstration was working well scientifically, Michelle and Grant expressed reservations that the demonstration would no longer be engaging for students and that they weren't sure how to make the demo more engaging. In particular, they were concerned that the demonstration would not hold students interest, and that the temperature changes observable in the demonstration were not dramatic enough to illustrate the importance of the greenhouse gas absorption. At the conclusion of this study, the scientists had not yet done further work toward refining the demonstration or making it more engaging for students.

## **Discussion**

These data show that the climate scientist participants approached the curriculum development in a manner informed by their experiences in both scientific and educational groups. That is, scientists approached the educational work like scientists, but also like educators. The creation of the dual credit climate science course can be conceptualized as an exercise in high school curriculum design with very little scaffolding from the secondary education or learning sciences communities. With a few exceptions (such as logistical details required by having the dual credit course accredited by the university), the

curriculum creation followed a vision that reflected what the scientists valued in the climate science learning. From its inception, the scientists' realized that they themselves needed outside educational and pedagogical expertise to develop the high school course, leading them to collaborate with high school teachers and to include myself in the role of educational consultant.

Given the lack of scaffolds that would encourage curriculum development in a particular direction, it makes sense that the ways of knowing, doing and being with which the scientists were already comfortable would quickly come into the foreground. The ways that scientists normally structured their activities through collaborative investigation and problem-solving were also used in this new context. The structure of the curriculum development project mirrored the values of the scientists' professional community (i.e. it was collaborative, privileged scientific knowledge and tools, supported graduate and high school student learning, etc.). In addition, the development of particular activities such as the GHE demonstration also show how the scientists highly valued both deeply understanding and accurately representing the scientific principles involved in these activities. For the scientists, having a well-developed understanding of the phenomena at play through scientific investigation was a necessary first step before the pedagogical design work could take place.

This marriage of scientific and educational ways of knowing, being and doing in the curricular design work is noteworthy for two reasons: (a) it is an example of the use of existing strategies for participation in one context in a new context, and (b) it provides insight into how educators can best support scientists' educational learning trajectories. In the first case, the extent to which the participant's scientific ways of knowing, being and

doing informed their participation in the curriculum development project is a marked example of the ways that prior experiences shape participation in new communities. Past research has described the difficulties associated both with allowing students' past experiences to be made visible and leveraged in a designed educational environment (e.g. Tzou & Bell, 2008; Jackson, 2011) as well as the difficulties in designing learning environments that support transfer to new contexts (Lobato, 2006). For example, Jackson (2011) describes how students' social positioning and academic success in a math classroom were aligned with how math instruction was carried out in the home. One factor raised in Jackson's analysis was the lack of ways that student expertise was made visible and leveraged in classroom activities. There are a number of reasons why students' prior knowledge may be underutilized in a classroom, including the logistical difficulties inherent in teaching many students, a lack of appreciation for the ways out-of-school experiences and expertise affect students' success in learning environments, or a disinclination to view students practice and knowledge as expertise. The above analysis informs this discussion by examining a group that has an easily identifiable, well-accepted and visible expertise. This demonstration of how participants' scientific experiences (as both professionals in scientific fields and as students and teachers of science) influenced their participation in a new context, supports a model of education that is responsive to learners' existing culturally- and contextually-situated ways of knowing, being and doing.

One common stereotype of scientists is that they are poor communicators and educators, a circumstance attributable to a variety of factors including their use of complex or confusing vocabulary (Sommerville et al., 2011) to complications from their own high level of expertise (Nathan, Alibali & Koedinger, 2001) to disconnects between the norms of

communication in scientific communities and mainstream media (McBean & Hengeveld, 2000; Olson, 2009). The data shown here provide a broader perspective on scientists as communicators by showing the scientific and pedagogical considerations that scientists take into account in educational work. The participants in this study showed some level of understanding of the values, practices, understandings of possible challenges and supports for learners, and pedagogical strategies, though these were constrained by their own experiences as scientists, teachers and students. There was a wide set of experiences as educators in educational groups, from teaching ESL outside of the US (Michelle and Scott) or working as an environmental educator (Madeleine), to teaching undergraduate and graduate climate science courses (faculty and advanced graduate students). There was also a range of experiences as students of science that informed their design work. For example, Margaret and the graduate students were the most vocal about their valuing of authentic, problem-based learning. For the graduate students, this value may be attributed to the fact that many of them had had exposure to this form of teaching as students in either high school or college. Senior faculty may not have had those experiences as students, and would likely not have had them as recently. Margaret was likely influenced by the views and educational experiences of her own teenage daughter, her past outreach experiences (including those with high school students), and her partnerships with the high school teachers and other education professionals.

By highlighting the scientists' past experiences with educational groups, as both teachers and students, I do not mean to imply that participants in this study necessarily had sophisticated or well-developed understandings of pedagogically-relevant ways of knowing, being and doing. There were many important educational concerns that were

underemphasized in the curriculum development process, including issues of equity and attending to local educational goals. In addition, the scientists' approach to investigating common learning difficulties and educational approaches such as designing curriculum to promote active knowledge construction and building on prior knowledge was less systematic and formalized than their approach to ensuring the accuracy of the climate science content. Their existing pedagogical strategies were not always sufficient for the scientists to accomplish curriculum development in the manner they wished without outside support. For example, graduate students like Clara required guidance from the high school teachers and myself in order to write up their activities. They specifically needed support in thinking about logistical concerns, and understanding the prior knowledge of teachers and students. In addition, the scientists abandoned the greenhouse effect project after being unable to figure out how to make it engaging. These challenges imply that while scientists may have experiences that can be leveraged in educational activities, there is room for educational professionals to support the scientists' development along educational learning trajectories in this period of partnership (Linn, Songer & Eylon, 1996).

## **Conclusion**

Scientists approach education in ways that are consistent with their scientific ways of being in the world, and the values that they have as scientists. The scientists in this study valued authentic scientific activities that were representative of how scientists actually practiced science in their professional endeavors. They also placed a high priority on thorough understandings of the science and accuracy of the demonstrations used.

Furthermore, they used problem-solving strategies similar to scientific inquiry to investigate pedagogical and educational problems.

The wide range of scientific and educational experiences that scientists leveraged throughout the curriculum development project indicate that scientists are not “empty vessels” of pedagogical ways of knowing, doing and being. They have experiences as scientists, educators and students that inform the way they participate in educational settings. Instead of criticizing scientists for trouble communicating with the public, it may be more productive to examine what scientists’ goals are for their communication, what their existing strategies are for communication and education, and then seek to use those existing strategies as a starting place to further develop scientists’ communication and education expertise.

Scientist involvement will always be necessary at some level to support student engagement in authentic, contemporary, societally-relevant science. Many scientists, like those shown in this study, are interested in education, and have a variety of experiences as both scientists and educators that are relevant to their participation in educational work. Future work should seek a better understanding of the constraints and affordances of leveraging scientists’ existing scientific expertise in education work, as well as strategies building upon scientists’ prior educational experiences. Work that positions scientists as learners in educational settings may allow for a deeper consideration of the types of resources that scientists bring to the table and the obstacles they may face deepening their pedagogical expertise in these contexts.

## **Chapter 4**

### **Challenges and Strategies for Climate Scientists in Education:**

## **Crossing Borders Between Educational and Scientific Communities**

### **Introduction**

Designing environments for science learning that engage learners in societally-relevant, contemporary and authentic scientific practice will require educators and educational researchers to form effective partnerships with scientists with expertise in these scientific practices. For these partnership efforts to succeed requires an understanding of the challenges and opportunities of scientists' involvement, and an arsenal of strategies to bolster cooperative and effective collaboration between teachers, assessment experts, students, learning scientists, natural scientists and technologists. However, methods for encouraging scientist participation in education, and addressing challenges that arise as scientists make their way into educational work is an open area of educational research. This study describes challenges that arose when scientists attempted to cross boundaries out of the subculture of science into educational arenas to support teachers' and students' developing expertise in the practices of climate science. Attending to scientists as participants in the cultural practices of scientific communities, I suggest strategies for addressing the observed challenges and promoting the involvement of climate scientists in curriculum development and enactment.

Students learning science have been described as having to cross borders into a subculture of science (Aikenhead, 1996). This border crossing is fraught with potential pitfalls, as students seek to align their existing worldview with the cultural views of science. To participate successfully in a scientific subculture, students need to appropriate scientific language, discourse and knowledge construction practices (Lee and Fradd, 1996;

Lemke, 1990). However, it is not just students who cross borders. Aikenhead (1996) describes the border crossings that academic professionals experience in their everyday lives:

In our everyday lives we exhibit changes in behavior as we move from one group of people to another; for instance, from our professional colleagues at a research conference to our family at a reunion. As we move from the one subculture to the other, we intuitively and subconsciously alter certain beliefs, expectations, and conventions; in other words, we effortlessly negotiate the cultural border between professional conferences and family reunions (p. 6).

When entering a new context, we all must learn to navigate the cultural norms of that context. As Aikenhead says, sometimes this is “effortless,” but when entering a novel culture, like science learners in a classroom, this negotiation takes more effort.

Just as students of science may find it challenging to cross *into* the subculture of science, it is also challenging for those who work primarily within the scientific subculture to cross *out* of that subculture and into the classroom. However, in order to participate in educational settings, that is exactly what scientists must do; they must cross out of their own accustomed subculture and into the classroom or educational culture. In this study, I describe that, just as students require support to cross borders between subcultures, so to do scientists require support when navigating between scientific and educational contexts. Specifically, I examine the challenges that scientists in two curriculum development and enactment projects faced when supporting teachers’ and students’ participation in particular cultural practices that required learners to use scientific technology, act

according to accepted social norms of the scientific community, and understand how particular scientific practices were used to create scientific knowledge.

## **Theoretical Framework**

### *Conceptualizing Expertise*

When taking part in educational programs, scientists are often called to play the role of a scientific expert. Experts are commonly distinguished from novices on the basis of conceptual understandings. Bransford, Brown & Cocking (2000) describes experts as those that “have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment. This, in turn, affects their abilities to remember, reason, and solve problems.” This perspective is knowledge-centric in that it implicates acquisition of “extensive knowledge” as the key factor in discriminating between the ways that experts and novices might think or act. That is, as experts increase their knowledge in an area, they develop particular ways of accessing and using this knowledge. Bransford describes characteristics of experts that include recognizing patterns and problem types, particular schemas for information organization, having knowledge that is contextualized, and fluent retrieval of information (p. 31). Experts are further described as falling into two groups— virtuoso experts and adaptive experts. The main characteristic distinguishing these two groups is that adaptive experts are able to learn new information and apply it to new problem-solving situations, whereas virtuoso experts perform particular operations with a high degree of skill.

This knowledge-centric view of expertise underemphasizes the other kinds of

expertise needed to participate in a particular setting as an expert. Collins and Evans (2007) expand the idea of expertise to include dispositions and performance. In their “Periodic Table of Expertises,” they describe a range of possible expertise, including the mastery of language, the ability to judge the expertise of others, and to competently complete an activity (p. 14). Ericsson (2009) is similarly concerned with performance as a way to assess expertise, though the performance assessment described continues to rely heavily on a conceptualization of “knowledge” as underpinning performance. While this description does lay out multiple dimensions for learning, the knowledge-centric descriptions of expertise may ultimately obscure some of the difficulties learners face as they strive to participate as an expert in a context, as well as those that those who already participate in a context face in supporting others’ developing expertise. Thus, I am concerned not only with what experts *know* but also what they *do*, and how what they know and do is informed by the cultural norms and values of the communities in which they work.

### *Dimensions of Scientific Expertise*

Scientists not only *know* science, they are also able to *practice* science and work according to cultural norms and values of the scientific community. Recent consensus reports on science learning that take a sociocultural perspective identify six dimensions of science (NRC 2007, 2009). These consensus research reports suggest that learning environments should provide students with experiences across all six strands to support their participation in scientific communities. The six strands include increasing

disciplinary knowledge, but also supporting expertise in scientific practices such as argumentation and experimentation, and supporting learners identification with and interest in science. The recently developed conceptual framework for science education, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, similarly places an emphasis on dimensions of science learning beyond content knowledge (NRC, 2011). In particular, this framework is concerned with scientific practices, and the intersection of knowledge and practice: “Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements— knowledge and practice—are essential” (p. 2-3). This framework identifies eight scientific practices as important across many scientific disciplines, and as essential for science learners:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information (ibid, p. 3-5)

These practices open up important cognitive, social and cultural learning processes for students, and are in line with what scientists do in their own professional lives; mastery of these practices is necessary in order to effectively contribute to a scientific community.

Working scientists, then, have expertise not only in the content knowledge of their discipline, but also proficiency in these practices. This is not to say that a deep understanding of content is unimportant for scientists; expert participation in science requires the coordination of this conceptual understandings with the scientific practices. For example, appropriate analysis of a data set (practice #4) requires a conceptual understanding of the data and the mechanisms that undergird patterns in the data. A persuasive scientific argument (practice #7) must be situated in and speak to the larger body of scientific knowledge. A deep expertise in scientific practices relies upon, but is not limited to, conceptual understandings.

Effective participation in scientific practices within a scientific community further requires the understanding of the social norms and values that govern these practices. To some extent these norms vary across disciplines and scientific communities (e.g. Knorr Cetina, 1999). While these norms are not formally called out in the NRC Framework, the Framework does recognize the importance of attending to these social norms that govern the workings of scientific community:

Finally, science is fundamentally a social enterprise, and scientific knowledge advances through collaboration and in the context of a social system with well-developed norms...In short, scientists constitute a community whose members work together to build a body of evidence and devise and test theories. In addition, this community and its culture exist in the larger social and economic context of their place and time, and are influenced by events, needs, and norms from outside science, as well as by the interests and desires of scientists. (NRC, 2011, p. 2-3).

Expertise in science requires that an individual be able to participate fluently in this social

enterprise. There is then implicated an expertise in navigating the social context of scientific work— knowing how and when to collaborate, how to write an email to a colleague, how to frame work for successful grant proposals— that is necessary for effective participation in scientific work. This facet of expertise is similar to Collins & Evans (2007) framing of expertise that includes social factors such as mastery over language and perception by peers (the meta-record of expertise).

What is necessary to be able to participate in scientific practices? Duschl (2008) argues that science learning should include conceptual, epistemic and social dimensions of knowledge:

- the *conceptual* structures and *cognitive* processes used when reasoning scientifically,
- the *epistemic* frameworks used when developing and evaluating scientific knowledge, and
- the *social* processes and contexts that shape how knowledge is communicated, represented, argued, and debated. (p. 277)

Preparing students to participate in science requires supporting their increasing expertise across these three dimensions. Participation in the subculture of science requires conceptual understandings, facility with using these understandings within the epistemic frameworks of scientific knowledge construction and the cultural values and social norms of the community.

In addition to these three dimensions, scientific work is enabled through the use of particular tools and technology. Pickering (1995) describes the work of scientists as a “mangle of practice” in which scientists and instruments form a dialectic, a “dance of

agency.” This dance is an “evolving field of human and material agencies reciprocally engaged in a play of resistance and accommodation in which the former seeks to capture the latter” (p. 25). Participation in science requires knowing how to use, interpret, and invent new technologies that enable individuals to take part in this “dance.” Thus, in addition to the three dimensions outlined by Duschl (2008), it is important to explicitly attend to the needed expertise in using scientific tools and technology when exploring expertise in scientific practices.

I conceptualize scientific practices as a type of cultural practice, and effective participation in scientific practices within a scientific subculture as existing across four dimensions: deep conceptual understanding of relevant scientific knowledge, proficiency with appropriate tools and technology, epistemological understanding how the practice leads to the construction of scientific knowledge, and social values and norms that guide the accepted use of the practice. This view of scientific practices is shown in Figure 3. Expertise in a particular scientific practice is understood to be situated within a particular scientific discipline or community, and to require a situated expertise in each of these four dimensions.

This study addresses how individuals deeply immersed in the subculture of science support teachers’ and students’ increased participation in that subculture. I explore how scientists struggle to recognize their proficiency in cultural practices as expertise and to support learners’ developing expertise in these practices. I explore the relationships between the four dimensions of scientific practices and how these dimensions manifest in scientist-teacher and scientist-student interactions. I then examine an implication of this

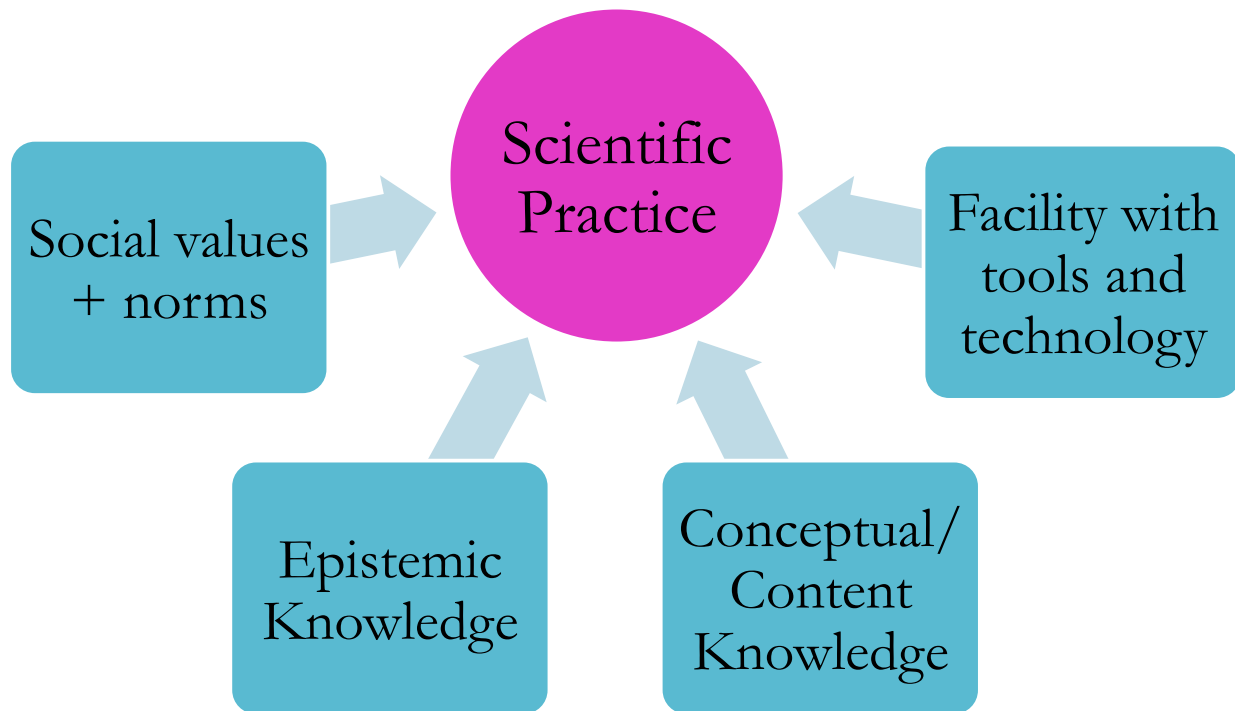


Figure 3: Model of scientific practice across four dimensions

conceptualization of practices, in the difficulty scientists' had anticipating challenges for learners across these four dimensions. This last is conceptualized using the idea of an *expert blind spot of scientific practices*.

#### *Expert Blind Spot*

Research into the nature of expertise has shown that experts not only have acquired a large amount of content knowledge within a particular domain, but also organize this knowledge in differently than novices do (Bransford et al., 2000, p. 32). In addition, experts have practiced within their field for so long relevant cognitive processes have become automatized, leading to fluent retrieval of information (p. 44). Experts are often unable to predict which concepts will be most challenging for learners; this phenomenon is

termed an *expert blind spot*. An expert blind spot arises because while the organization and automatization of these processes are valuable to experts engaged in work within their own field, they may hinder the effectiveness of experts as teachers (e.g. Nathan, Alibali & Koedinger, 2001).

It is not enough, then, for individuals to have a deep disciplinary knowledge, they must also have pedagogical content knowledge to support novices' developing conceptual understanding. Shulman (1986) argues that effective teaching requires both domain-specific conceptual and pedagogical content knowledge. Pedagogical content knowledge includes the knowledge necessary to teach a subject effectively, including "the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9). Work with pre-service and in-service teachers in science, language arts and math (Grossman, 1990; Nathan, Koedinger & Alibali, 2000; Nathan & Petrosino, 2003) and music (Schmidt & Canser) indicate that teachers with a high level of disciplinary expertise may be less effective as teachers when they do not also have the required pedagogical content knowledge.

In this analysis, I extend the idea of an expert blind spot to include other ways experts are likely to differ from novices. In this study I explore how in addition to anticipating conceptual challenges, scientists struggled to anticipate challenges for learners across the three other dimensions of scientific practice, the epistemic, social and technological dimensions. That is, scientists who cross borders between scientific and educational settings may have be surprised by the supports needed to promote learners

growing participation in scientific social norms and values, understandings of scientific epistemology, and facility with particular tools and technologies.

## **Methods and Study Design**

### *Study Contexts & Data Sources*

This study draws from two curriculum development and enactment projects in which scientists played critical roles. Both curriculum development projects focused on climate and climate change science, and the scientists involved work in areas related to climate change or climate impacts. The two projects are similar in that they share the goal of engaging high school students in authentic scientific technology (though the Ecological Impacts of Climate Change Unit is more systematically grounded in scientific practices) and cutting-edge content knowledge. They differ in the roles that the scientists play in the development of the curriculum, the level of involvement of the scientists with teachers and educators, and the relationships among the scientists, and the degree to which they leveraged technical knowledge of learning and education. An overview of these two settings is provided in Table 4.

### *Setting 1: Dual Credit Climate Course<sup>12</sup>*

The first curriculum development project is a scientist-led effort to adapt a college-level climate science course into a course for advanced high school students. This course is “dual-credit,” that is high school students enrolled in this course would receive credit from

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<sup>12</sup> This context is first described in Chapter 3 of this dissertation.

Table 4: Overview of Study Contexts

	<b>Title</b>	<b>Brief Description</b>	<b>Scientists</b>	<b>Students</b>	<b>Teachers</b>
Setting 1	Dual- Credit Climate Course	Scientist-designed adaptation of a university-level climate change course for advanced high school students	20+, varying levels of involvement	0	10
Setting 2	Ecological Impacts of Climate Change Unit	Two six-week long pilot enactments of project-based curriculum for use in underresourced communities	14	~50	2

the university in addition to high school credit. The curriculum was adapted almost entirely by the climate scientists, with an advisory board of scientists and educators. During the first year of the program, the scientists recruited ten high school teachers to participate in professional development for the course, with the aim of creating a community of scientists and educators interested in promoting climate science education. Roughly fifteen graduate students from the CCG were recruited by the project leads to supplement the curriculum with hands-on activities that used authentic scientific data and practices. Some of these students received credit as part of a graduate certificate program for their participation in the project (though not the research study), some were volunteers and some were partially funded by the project.

The curriculum development began in the fall of 2010, and data was collected through the first year of the project, ending in fall of 2011. During this year, I acted as an

educational consultant on the project, attending meetings and helping graduate students with the design and implementation of their activities and lessons. This project included two professional development workshops— a day-long workshop in March 2011 and a week-long summer institute in June 2011. In these workshops, scientists and teachers shared materials, collaborated on lesson plans, and toured university facilities. The curriculum was designed as a year-long course that incorporated projects and activities that drew on scientists' research and scientific tools that were integrated into a course built around an earth science text book (Kump, 2009). Some teachers decided to modify the course into a semester of an AP Environmental Science course. In order for their students to receive university credit, teachers had to have their homework and tests checked by the scientists to make sure they covered the necessary material.

*Setting 2: Ecological Impacts of Climate Change Unit<sup>13</sup>*

The second context encompasses two pilot enactments of an Ecological Impacts of Climate Change curriculum that occurred in spring and fall of 2011. This climate change curriculum is a subset of a larger curriculum development effort. The overall goal of this effort is to create several year-long courses in English Language Arts, life sciences and algebra for high school freshmen. Course development is led by learning scientists in collaboration with disciplinary experts, classroom teachers, and video producers. These courses aim to re-imagine what is possible in a classroom setting by incorporating cutting edge technologies, social networking, contemporary content, authentic disciplinary practices and access to world-class experts.

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<sup>13</sup> This context is first described in Chapter 2 of this dissertation.

The life science course is designed using a design-based research approach with an eye to giving students opportunities to engage in authentic scientific problems, to utilize scientific practices such as performing fieldwork, analyzing and using computer models, and writing scientific texts. The Ecological Impacts of Climate Change unit culminates in a final project in which the students team up to create an infographic, a visual, data-based display that communicates an argument about ecological climate impacts and why these are important to human populations. Because of my background in oceanography and climate science, during the development of this project, the curriculum development team highly leveraged my background in climate science and connections to the local climate science community. The curriculum used Remix, a social media platform, that connected students to each other and also to disciplinary experts. In this platform, students could form interest groups, debate material in online forums, and share work with their peers, teachers, researchers and disciplinary experts in the field. These disciplinary experts— a mixture of ecologists, oceanographers and atmospheric scientists in the climate change unit— reviewed student work, interacted with students via Skype, and visited the classroom.

Because I drew on my contacts in the climate science community when recruiting participants to be experts in this unit, there is some overlap between the participants in the two settings, and the majority of the participants who do not overlap are members of the same university community.

### *Data Sources*

This study draws on multiple data sources from both contexts, including

observations of classroom enactments, meetings and professional development workshops; interviews with teachers, students and scientists; exit surveys with scientists; curricular artifacts including scientists-created curricular materials, student work and scientist feedback on student work; qualitative field notes; teacher and scientist daily exit surveys from professional development workshops and weekly student engagement surveys from pilot enactments. The scope of these data sources are outlined in Table 5.

### *Analysis*

Analysis was conducted through iterative passes through the data corpus to identify and describe emerging themes in the data relating to scientific practices, social, epistemological, conceptual and technological dimensions of scientific practices, expert instruction of scientific practices, challenges for experts, and expert blind spot of scientific practices. Because of the size of the data corpus, field notes and surveys were reviewed first to identify instances of challenge for the scientists, teachers or students involved in the studies that related specifically to scientist involvement. Video and audio recordings directly referred to by those sources were then selected for transcription, and the emergent themes described above identified using Dedoose, an online analysis tool. Other relevant video and audio recordings were then identified and selected for transcription and analysis of scientist-educator and scientist-student interactions, and this repeated iteratively. The observations and interviews (the video or audio recorded sources) were triangulated whenever possible with surveys and field notes. During this process, I used memos to connect pieces of the data that centered on various challenges and strategies of

Table 5: Overview of Data Sources for Two Settings

<b>Data Source</b>	<b>Dual-Credit Climate Course</b>	<b>Ecological Impacts of Climate Change Unit</b>
<b>Observations</b>		
Classroom	N/a	~60 hours (30 per enactment) video + audio + field notes
Meetings	~15 hours audio + field notes	N/a
Prof. Dev. workshops	~50 hours video + audio + field notes	N/a
<b>Interviews</b>		
Scientist	~10 hours video + audio + field notes	~5 hours, (Spring 2011) audio + field notes
Student	N/a	~6 hours (2 hours Spring 2011; 4 hours Fall 2011) video + audio + field notes
Teacher	~5 hours video + audio + field notes	~2 hours (1 per enactment) video + audio + field notes
<b>Surveys</b>		
Scientist	30 daily exit surveys during PD workshop	9 post-enactment exit survey (Fall 2011)
Student	N/a	Weekly engagement surveys (4, Spring 2011; 5, Fall 2011)
Teacher	42 daily exit surveys during PD workshop	N/a
<b>Artifacts</b>		
	<ul style="list-style-type: none"> <li>• Iterative drafts of lesson plans</li> <li>• Documents relating to arc of curriculum, including</li> </ul>	<ul style="list-style-type: none"> <li>• Student work</li> <li>• Pre- and post-assessments</li> <li>• Student posts on social networking platform</li> </ul>

	learning goals <ul style="list-style-type: none"> <li>• Workshop presentations</li> <li>• Digital photographs</li> </ul>	<ul style="list-style-type: none"> <li>• Digital photographs</li> </ul>
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the scientists, and to begin describing patterns and themes in the data corpus; and searched for confirming and disconfirming data, as described by Erickson (1986).

After this iterative process and using the memos created, I constructed the framework for scientific practices described earlier. In an attempt to constrain the scope of this study, the final pass focused only on challenges related to the four dimensions of the framework of scientific practices. This analysis identified moments relevant to the four dimensions of scientific practice and instances of, or implications of expert blind spot. During this process, notes were also taken of challenges in scientist-educator or scientist-student interactions that did not relate directly to these dimensions (e.g. power dynamics, logistical challenges) as a potential focus for a later study. After the analysis was completed, I spoke with various key informants as a member checking process.

## Major Findings

In both study contexts, scientists supported teachers and students in their participation in authentic scientific practices. In the Dual-Credit Climate Course, scientists created lessons that focused on the scientists' own research interests and practices and the practices and understandings necessary to interpret written accounts of climate science research, in particular the IPCC reports. In the Ecological Impacts of Climate Change unit,

scientists supported students as they analyzed climatological and ecological data, and wrote and communicated arguments based off of this and other scientific evidence. While the instances described in this analysis describe challenges faced by scientists and educators, this shouldn't overshadow the positive and successful aspects of these interactions. My aim is to highlight areas in which scientists' expectations for participation were in tension with educator and student participation, in order to improve scientist-educator interactions in the future.

The examples in this section underscore three main challenges scientists had when supporting teachers and students participation in climate science practices. Scientists had difficulty: 1. Anticipating high-challenge areas for novices in scientific practices, 2. Gauging the appropriateness of student work, and 3. Appreciating their own expertise in areas related to scientific practices that were not directly tied to content knowledge. These three themes are interrelated, and are explored below.

### *1. Anticipating challenging aspects of science practices*

In the design of new activities and lessons as part of the Dual-Credit Climate Course, scientists at times struggled to identify and scaffold teachers and students work in new scientific practices. These activities and lessons were often tied to scientists' area of research. Because scientists were able to choose topics of interest, the scientists tended to have a high level of proficiency in the particular area in which they created materials. For example, Madeleine, a paleoceanographer created an activity using ice cores to understand earth's past climate, while atmospheric scientists Scott and Curtis created several activities

around atmospheric circulation. These activities were developed into a prototype stage in the year leading up to the June professional development workshop with the teachers, and were then presented during this workshop. The format of these presentations varied, but in most cases the teachers were given the opportunity to try the lesson or activity and then provide feedback. Teacher feedback generally focused on what would need to be changed or further developed in order to make the activities useable in a classroom, and the teachers also speculated on what aspects of these activities would be challenging for their students.

During the professional development workshops, the scientists were at times surprised by both the teacher feedback and by aspects of the activities that the teachers found challenging. The scientists found that the challenges and questions they anticipated were not necessarily the challenges that actually occurred. For example, on the second day of the professional development workshop, we spent the morning discussing climate models and playing with a simple climate model that scientist Margaret had programmed into Microsoft Excel. A significant portion of the afternoon was spent conducting an activity on climatological data analysis in Excel designed by graduate student Clara. Both of these Excel-based activities surfaced challenges that were not originally anticipated by the scientists. Anticipated and actual challenges experienced on this day are listed in Table 6.

Table 6: Anticipated and observed challenges for the Excel activities

Anticipated Challenges	Observed Challenges
<ul style="list-style-type: none"> <li>• Conceptual understanding of model components</li> <li>• Understanding the differential equation</li> </ul>	<ul style="list-style-type: none"> <li>• Working collaboratively on projects</li> <li>• Basic user fluency in using Excel as a tool for scientific modeling practices</li> <li>• Valuing teaching and using mathematical software, like Excel</li> <li>• Using the model to generate new knowledge (i.e., what kinds of questions could it answer)</li> <li>• Understanding mathematical manipulations to make the equation cleaner</li> <li>• Wanting to know where all the parameter values came from and how they had been calculated</li> </ul>

The scientists anticipated challenges with the climate modeling activity of a mostly conceptual in nature. For example, they expected that understanding the differential equation and the model components (i.e. understanding what a “forcing” is and reasoning quantitatively about forcings in the model) would be difficult. However, there were significant challenges for the teachers in using the model before they were able to reach

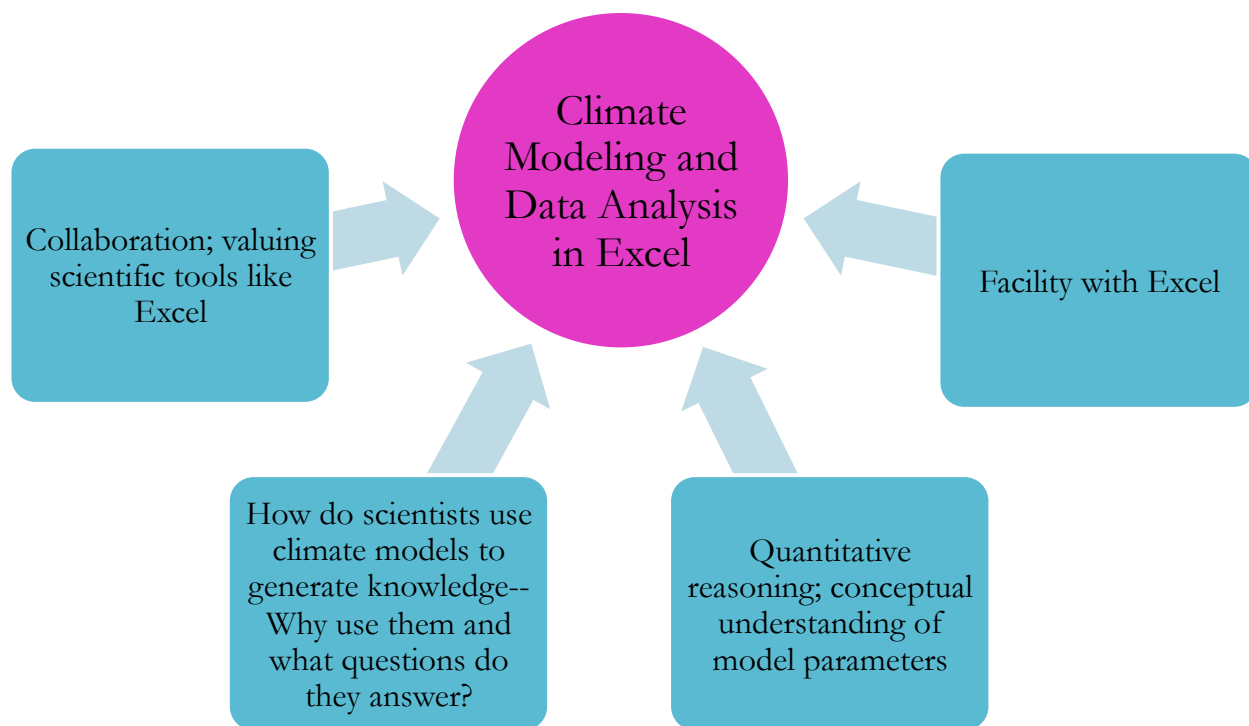


Figure 4: Dimensions of the Scientific Practice of Climate Modeling

this level of quantitative reasoning.

In their exit surveys for the day and in their conversations during and after the activities, scientists noted that some of what the teachers found challenging was unexpected; these challenges relate to the four dimensions of scientific practices, as shown in Figure 4. For example, scientists noted that the teachers' norms around collaboration were different from their own. This particular group of scientists is extremely interdisciplinary and highly values collaboration of individuals with varying expertise across disciplines. Some scientists noted that they expected the teachers to approach problem solving in the Excel activities in a more collaborative, team-oriented manner but that didn't happen. One graduate student commented in her exit survey:

I was so excited for teachers to complete the excel assignment-- but then I was dissatisfied[sic] that a) they didn't know excel b) they didn't work together as much c) it seemed like they were in a competition and didn't want to team up.

This graduate student didn't anticipate that the teacher community did not share the same social norms that governed her scientific subculture. One possible explanation for this is that most of the teachers didn't know each other, so they may have been reluctant to team up. It is also possible that in their own teacher communities they do not collaboratively problem solve in the same way that the graduate student does in her scientific community. Finally, it is possible that the teachers felt uncomfortable in the space and with each other, and were reluctant to team up in a threatening space. Whatever the reason, the fact that the teachers were not as highly collaborative as expected by the graduate student was "disappointing" and, as she told me at the end of the day, made her less excited about the educational experience. Supporting collaboration was not originally a dimension of the learning environment that scientists attended to, as they expected it to happen organically. While the root of the collaboration issue is not clear, potentially caused either by social threats in the space that discouraged collaboration or by differences in teacher and scientist collaboration norms, from this experience, some of the scientists recognized the difference in the expected and observed collaboration among the teachers, and could potentially begin to address the underlying cause to support future collaborative learning experiences.

Scientists were also surprised that many of the teachers were not very familiar with using Excel— the tool needed in these activities for the scientific practice of climate

modeling and data analysis. While some of the teachers were proficient with Excel, others needed support in basic Excel features such as using functions (e.g. finding averages), or creating plots. In addition, teachers were divided about whether or not it was worth the time in class to teach Excel, that is they did not necessarily highly value student proficiency in this tool. In the exchange below, teachers Mark and Jerry discuss the value of the activity on climatological trends they've just completed with graduate students Clara (who designed the activity) and Madeleine. In the Excel activity, Mark and Jerry struggled to complete the task, spending nearly twenty minutes trying to figure out how to calculate an average.

1. **Mark:** Basically we've spent 25 minutes learning how to use Excel,
2. **Clara:** Yes.
3. **Mark:** We're really not analyzing any data whatever.
4. **Clara:** Right, I mean I could very easily give them [the students], the prob--
5. **Mark:** You could do a different version, you could do both versions. But if you had a version in which they already had the plots-- I got-- I would like kids drawing best fit lines to this.
6. **Clara:** Uh-huh.
7. **Mark:** But, ah, um, and maybe--
8. **Clara:** Like, I can very easily get them— Excel filled out to the point where all the columns that I had you guys calculate are already there.
9. **Mark:** Are already done.
10. **Clara:** And they would just make the figures.

11. **Mark:** Well, yeah. I guess it's a good idea to teach them how to do these things.
12. **Madeleine:** I thought that this was a useful activity because Excel's a useful tool.
13. **Clara:** Right.
14. **Madeleine:** And they'll need it in other classes and they would make it a real science, like—
15. **Mark:** Here's a theory, just--
16. **Jerry:** There's probably like half of my kids won't have any problems with the Excel thing.
17. **Mark:** Really?
18. **Jerry:** The other half will stumble all over the place.
19. **Mark:** It's just that, that thing about, you know, how much time do we allow to actually do this in our classes and then, you always seem to be running out of time.

In this excerpt, Mark and Jerry are concerned with the fact that the Excel task is time-consuming and may be potentially challenging for their students. They are unsure of whether or not the time-commitment necessary to teach Excel is worth it, especially since, as Mark says in line 19, “you always seem to be running out of time.” Teachers are under enormous pressure to cover a large amount of content, and adding in time to teach a tool like Excel is not necessarily something that will work within the constraints of their classroom. In addition, Mark did not necessarily view the data processing done in the Excel activity as data analysis. To him, the twenty-five minutes he had spent had not contributed

to the data analysis, and this doesn't seem to be time well-spent as he says: "We're really not analyzing any data whatever." This is in part an epistemological issue, as Mark viewed "analysis" as correlating "best fit lines," whereas for Clara finding and processing the data in preparation for the statistical analyses was an important step in the knowledge construction process. To address Mark's concern, Clara suggested some modifications to the Excel sheet that would allow students to more quickly be able to play with the plots and the lines of best fit to the data, and the discussion turned to whether or not teaching Excel is a valuable use of class time.

Clara and Madeleine hold the perspective that within the scientific culture Excel is a necessary and important tool. As Madeleine mentions, college-bound students will need to be able to use Excel for their coursework. Proficiency in the tool is connected to specific practices relating to data visualization and analysis competencies. After this excerpt, staff member Lilian comments that students at the university need to know how to use Excel, and faculty member Margaret raises the concern that doing this kind of data analysis is important, and that students may not have a chance to do this in their other high school classes. In her exit survey, Clara noted that she found this exchange and the negotiation between the scientists' and teachers' values challenging: "[One thing that was challenging was...] People thinking excel was hard and not seeing the value of working through it --> i.e. learning excel was the point of the project and people where[sic] missing that."

In addition to conflicts between the social norms (collaboration) and values (of Excel) apparent in these activities, there were also further difficulties on epistemological dimensions. As they worked through the Excel climate model activity, the teachers and

scientists discussed how the model worked and how it could be used in a classroom. The Excel sheet had three tabs, and each of these three tabs had a slightly different way of running the model. As the teachers interacted with the model, they had trouble figuring out what exactly these models could be used to demonstrate, and how this related to similar models in the IPCC report. In the excerpt from the climate model activity below, teachers Mark and Jerry discuss the model with Margaret, who created the Excel sheet. Mark had trouble recognizing how the model Margaret created relates to the kinds of plots he has seen before (e.g. carbon dioxide emissions scenarios):

**1. Mark:** OK, so, what I want my students to get is that there's var-- there's variation in the future outcome during their lifetime depending upon different scenarios we use in regards to the different amount of CO<sub>2</sub> we create, and so you're familiar with that graph-- [if humans take] no action, it [CO<sub>2</sub>] doubles in ten years, right, you get this three to twelve degree temperature rising. If I can have an Excel sheet like this, you know, in which I were to say to the kids: "OK now if we do, you know if we cap CO<sub>2</sub> at this emission then in a hundred years this is what the graph is going to look like. If we do absolutely nothing then CO<sub>2</sub> emissions is going up by, you know, um, double in twenty-five years. And this the curve that temperature is going to get." That would be a really, really great, you know--

**2. Margaret:** I mean, you can do that with this. You can-- cuz this, in the under here one *((selects a different tab on the Excel sheet))* you can say, OK

I'm going to turn off this noise, we just won't use that right now.

3. **Mark:** Uh-huh.

4. **Margaret:** And you turn off the volcanoes. And this is my linearly increasing over a hundred years and then I go down here *((scrolls down the Excel sheet))* and I say OK this is the temperature in a hundred years.

5. **Mark:** Right, and that would be if CO<sub>2</sub> continues to rise at the same amount that it's rising right now, right? And that's where I get the linear relation between CO<sub>2</sub> and temperature.

6. **Margaret:** Right, and then if I doub-- if I double that [the amount of carbon dioxide], make this a two instead of a one, then you can see that the temperature increases.

7. **Mark:** Right.

8. **Margaret:** So that is something you can do with the way it is right now. And then you'd have to make a key or turn that number [the amount of carbon dioxide] into ppms [parts per million, a concentration unit] or something, I mean that's easy to do.

9. **Mark:** And, and that, I would assume that there is no feedback mechanisms.

10. **Margaret:** No, the feedbacks are in there. The feedbacks are in there. They're right there.

11. **Mark:** OK.

12. **Margaret:** They're still there. And that's that constant number that doesn't change.

13. **Jerry:** The number two there you said: "OK suppose we doubled," but what

if we do-- can we do something like a two percent increase per year?

14. **Margaret:** So this one-- this particular one-- if we go to the last one (*switches to last tab*)), this is a linear forcing so I've set what the size is at the end of the hundred years, so you could, you know change that.

15. **Mark:** So, CO<sub>2</sub> from zero to one hundred doubles by the end of one hundred, rather than going up two percent per year or one percent per year?  
Is there a way to--

16. **Margaret:** You could-- you could code that to be a percentage increase each year. That's not quite the same thing.

Mark and Jerry discuss what the kinds of plots and scenarios they would like to be able to use with their students (capping CO<sub>2</sub> emissions, linear or percentage increases in CO<sub>2</sub>), but have difficulty recognizing which pieces of the Excel sheet answer which question, and how that relates to the parameters in the model that are changing. In line 2, Margaret shows Mark how his idea actually maps to the model as it is already written. However, there is confusion about whether or not the feedbacks (the model parameter that controls how much the increase in temperature is amplified or damped given a particular carbon dioxide increase) need to be turned off in order to create the plots Mark wants. The questions that Mark and Jerry ask revolve around how to use the model to generate particular kinds of information. That is, they have to do in part with a quantitative understanding of the model and its parameters, but they also have to do with recognizing and testing the capabilities and function of the model. Understanding how climate models can be used as a tool for scientific knowledge generation, and which models are appropriate for answering

which questions, is an epistemological problem.

In addition to this epistemological dimension, there were also conceptual challenges beyond what the scientists anticipated. Though the scientists tried to scaffold teachers' understandings of climate modeling by providing a lecture on the topic before having the teachers tackle the Excel climate model, teachers felt that the conceptual complexity of the lecture and the activity was too great, and that the scientists needed to begin at a simpler level. Several of the teachers noted that they found this day challenging (and suggested ways to improve) in their exit surveys. One teacher commented: "I had a little trouble following the global modeling exercise, but eventually I caught on," while another noted they had trouble keeping pace with the scientists: "Talks by scientists are very fast + Hard to absorb (but great to see their work). Having a hard time under all the math, chem. + physics of it all." A third teacher also commented that they found the complexity to be problematic, stating that one challenge they had was the "Climate model intro this morning. Too complex right at the start of the day. Start simple! Or, perhaps should have assigned reading of the relevant text on climate models before the lecture."

Part of the challenge for the teachers may have been that the scientists did not anticipate what the teachers found to be mathematically and conceptually challenging. For example, one graduate student commented on the difference between what he thought would be challenging for teachers and the questions teachers actually asked: "It was really interesting to see what the teachers got hung up on. It didn't necessarily match up with what I thought. For example, how is 'b' calculated instead of what is a forcing, or what is noise?" Throughout the climate modeling activity, teachers asked a lot of questions about

the specifics of how parameters were calculated (such as forcing parameter “b” which appears in the differential equation). They also struggled at times with manipulations that had been done to the equation to make it appear cleaner, such as multiplying by terms that made the units “easier.” Many of these questions were framed by the teachers as ones they anticipated their students asking (e.g. “What would be a really good example to give to a kid...”, “If I was to explain this to my class...”). For the purpose of the climate modeling activity, however, the specific values of the numbers were less important to the scientist than the relationships and interactions between the model parameters, and how “playing with” the model could be used to generate new information.

One graduate student commented on this difference between how teachers approached understanding new material and how he approached the material:

[One thing I learned was...] It’s really import to start simple + at the beginning, because a lesson is lost the moment people can't follow. Also, in this case they weren't necessarily interested in learning the material-- they were interested in how to present the material to their students.

This distinction between understanding scientific material in order to be able to participate in the generation of new scientific knowledge and understanding scientific material in order to be able to teach the material to others is an important one, and lies at the heart of the tension between disciplinary expertise in scientific practices and pedagogical expertise in scientific practices. To effectively support student participation in scientific practices,

the teachers needed to be able to not only achieve a level of mastery of the practice itself, but also anticipate challenges for their students.

## *2. Recognizing own scientific expertise*

The above climate modeling example illustrates how scientists under-anticipated not only conceptual challenges for novice climate modelers but also under-appreciated the role of social norms, epistemological understandings, and proficiency with scientific tools and related practices. One implication of this is that scientists may under-appreciate their own scientific expertise in areas related to the cultural practices of science. This phenomenon of under-appreciation of expertise was notable in instances where scientists were working directly with students in classroom enactments. Despite the high level of expertise that scientists had and demonstrated in their interactions with students, some scientists felt that they were not in fact utilized as “experts.”

For example, Scott and Isaac are two atmospheric science graduate students who participated as experts in the Ecological Impacts of Climate Change unit. Both of them critiqued student work and visited the classroom for students’ culminating presentations, and both felt that the work they did with the students did not require a high level of expertise. However, the feedback that they provided to the students did in fact require a high level of scientific expertise, particularly around the scientific practices of argumentation and communication.

The following series of excerpts is from Scott’s feedback on student Walt’s final project. In this feedback, Scott provides positive comments and suggestions for how Walt

can strengthen his argumentation. He also provides feedback on the visual presentation and clarity of Scott's message and argumentation, an important scientific practice associated with communicating scientific information via scientific posters (Scott's feedback in its entirety are contained in Appendix J).

Hi Walt!

Overall this is a fantastic start. Visually the poster is appealing, the scientific information is well researched, and the topic is important. Your main focus now should be to make it clear how and why forests are affected by climate change, list out why people should care about this, and just connect the dots between cars and trees (see my comments below). I really look forward to seeing the final product on this.

...

- The graphic in the upper right and left corner is a great illustration of the greenhouse effect! The explanation is awesome. The "Reflected photons" aren't actually "reflected" but are "re-emitted" (and in all directions, not just down). Really great job here! I am impressed by the explanation.
- It might be helpful to include the temperature graph over time to show that temperature has increased this past century (to add to your greenhouse effect figures). You have a great theoretical explanation (i.e. why it warms), but didn't actually show that it warms (most people know this, so if you don't include a graph of temperature change it isn't too big of a deal).
- There is a good connection for: People drive cars petroleum is used more CO<sub>2</sub>

larger greenhouse effect Earth is hotter trees die off (this last step needs more information - either a text explanation, a picture with text, or a figure)

- Maybe you could make this logic clear with arrows from cars to petroleum use to increased CO<sub>2</sub> to a warmer Earth to dying trees) somehow. You could also include a text explanation that walks other students through this logic.

...

- I really like that you chose to research forests in global climate change. Forests are so important for many species and are so large that they can affect rainfall and temperature in different regions of the Earth. You are off to a fantastic start on your poster and I love the graphics you have picked out. Really good, creative work!

Thank you for that.

Most of Scott's feedback focused on increasing the validity of Walt's overall argument. He makes several suggestions for how Walt can make his argument more convincing by supplementing it with more evidence ("connect the dots between cars and trees," "It might be helpful to include the temperature graph over time," "this last step needs more information - either a text explanation, a picture with text, or a figure"). He also includes feedback on the effectiveness of Walt's infographic as a visual communication tool ("Maybe you could make this logic clear with arrows," "I love the graphics"). Visual communication is an important practice for scientists who often present their arguments via posters or presentations at meetings or conferences.

In addition to supporting Walt's argumentation structure and evidence, Scott also

provides feedback on the value of the argument Walt is making, and provides nuances in the conceptual understandings that underpin the argument. He tells Walt that “I really like that you chose to research forests in global climate change,” but says that Walt should include more information about “why people should care about this.” An important part of making a persuasive scientific argument is being able to show the relevance and value of the work. In their work, scientists decide which possible questions to pursue are of value, which are the important, interesting and relevant questions, and which are worthy of being funded. Being able to make a case for the value of one’s argument is an important social dimension to scientific argumentation. Finally, Scott is able to support Walt’s conceptual understanding of the science, for example nuancing fact that photons are “re-emitted” not “reflected” in the greenhouse effect. This demonstrates a high level of conceptual expertise on Scott’s part.

When Scott visited the classroom, he continued to support Walt’s argumentation. After Walt’s presentation, Scott asked a question of Walt in which he wanted him to clarify the mechanisms of global warming’s impact on trees:

1. **Scott:** I just want to understand this. So increase cars, increase CO<sub>2</sub>, increase global warming in the greenhouse effect. How do you, uh, hurt trees or kill off trees?
2. **Walt:** Um, well what this is doing is, uh, a lot of climate change is affecting weather and other weather patterns total that make climate, so what that does, it-- that affects plants because they're very time-oriented on the

seasons of when they're going to produce their seeds. And so if the seasons starts to change before the, uh, plants can readapt, that means that a lot-- there won't be much more reproduction of plants, so there'll be a lot less sprouts in the spring and so, uh, the populations will start falling.

In his question, Scott asks Walt to clarify his argument that increasing cars will harm forests. He repeats part of what Walt has said with respect to the logic of increasing cars increasing carbon dioxide and causing increased warming, but asks for an explanation of how this hurts trees. Walt answers this question by explaining that as weather patterns change, trees will change the timing of their life cycles "because they're very time-oriented on the seasons of when they're going to produce their seeds," and if the timing of seasonal changes shifts, trees that can't "readapt" may have "a lot less sprouts in the spring" and falling populations. In this instance, Scott recognized the missing link in Walt's argument, and by asking this question gave Walt the opportunity to strengthen his argument by demonstrating his understanding of life cycle changes and their potential impacts on forests.

In his interactions with Walt, Scott demonstrated a high level of conceptual understanding, expertise in scientific argumentation, and an understanding of what made particular scientific questions interesting and important ones. Similarly, Isaac also utilized his expertise in scientific argumentation when working with his students. Despite this level of expertise that Scott and Isaac utilized, both of them reported in their exit surveys that they felt like they hadn't been utilized as experts. This indicates that they didn't see the work they did as requiring significant expertise:

**Scott:** We weren't really utilized as experts and that may not happen - that is okay, but most of the things we were doing any adult could do.

**Isaac:** I don't know if there is a way to utilize our "expertise" more or to get more involved with the students to see them progress with their work.

Scott, who felt that “any adult” could provide the same level of feedback that he was called on to provide, doesn't recognize how his expertise in various scientific practices shapes the way he approaches scientific tasks like argumentation or visual communication. That is, his approach to argumentation is likely different from another adult who does not primarily work in this scientific subculture.

Scott and Isaac may have in part felt like they “weren't really utilized as experts” because to a large extent their feedback did not focus on content knowledge. While some conceptual understandings were obviously at play in the work they did, much of their feedback focused on practices and norms around argumentation that exist within their scientific subculture. Because “expertise” has traditionally focused on content knowledge, it might not be obvious to scientists like Scott and Isaac that many of the ways they supported students' participation in scientific practices were not be related to content knowledge. Like the scientists who created the climate modeling activity, Scott and Isaac may not have recognized the importance of attending to dimensions of participation scientific context that go beyond understanding content knowledge.

### *3. Gauging the appropriateness of student work*

Scientists at times needed support in evaluating the quality of student work, or in determining the level of activity that was appropriate in a high school classroom. Scientists needed advice from their teacher and educator partners to help them gauge their expectations of student performance (in the Ecological Impacts of Climate Change unit) and determine at what level they should design their lessons (in the Dual-Credit Climate Course). In many cases, especially when providing feedback directly to students, scientists had a tendency to have expectations for the students that were not in line with the performance expectations of the curriculum. While there are likely multiple reasons for this, one potential contributing factor is that scientists under-estimated their own level of expertise.

In the Ecological Impacts of Climate Change Unit, scientists were largely communicating with students via a social networking technology platform. While this was convenient for scientists and students in that it allowed them to asynchronously pass work back and forth to each other (i.e. the scientists could work on their own schedule and did not have to visit the classroom in person), it created some communication challenges between the two groups. The scientists were unable to see what happened in the classroom or hear conversations that the students had about the material, and thus had to evaluate student work only by what ultimately appeared on the page, and by whatever extra information the researchers and teachers passed along to them. Often, what ended up on the page lacked the depth of the classroom discussions. In addition, it was impossible for scientists to tell (without input from the researchers and teachers) whether

items were incomplete or blank because students found them challenging, or because students were not putting in the effort. The scientists tended to assume it was the latter, as shown in the following comments from the exit surveys:

**Isaac:** I perceived that many of the students...weren't trying very hard (e.g. would leave whole large sections of the assignments blank, or would just guess at the answers rather than attempting to go online and find them out), which made it hard to engage with them.

**Amy:** For some of the work I was trying to give students feedback on, it felt like they weren't really trying. That's frustrating for any educator and kind of sad. Also, it drove my nit-picky side crazy that the students had such poor spelling and grammar. In all honesty, as a scientist I find that people don't take me seriously when I'm sloppy and it would be well worth it for the students to learn in high school how to work at a high standard.

While there were instances in which the students “weren’t trying very hard,” there were also instances in which items were incomplete or blank because they were challenging for students, or because the students didn’t have enough time to complete the work. The scientists made these judgments in their exit surveys without a full understanding of the learners’ backgrounds, circumstances of instruction, or a refined calibration of high school student level work. The scientists in these exit surveys point out behaviors that they would expect from the students such as “attempting to go online” to find answers, or having

correct spelling and grammar. However, these suggestions presuppose students' proficiency in these practices. While Isaac has the necessary expertise to discern the appropriateness of information he finds online, the 9<sup>th</sup>-grade students he was critiquing may not have yet developed that expertise, or may not have developed it to the extent where this would be an "easy" thing for them to do. Likewise, Amy makes a valid point that as scientists, writing clearly and using proper vocabulary, spelling and grammar is incredibly important. In the unit, we decided not to emphasize these aspects (which were often challenging for our students), so that they could instead focus on other practices, such as using appropriate evidence in their arguments. Given the context of the classroom in which we were working, Amy's expectations for the students exceeded what could reasonably be expected.

These pilot enactments were the scientists' first foray into working with high school students in this manner, both to provide detailed, iterative critiques of student work, and to do so asynchronously using a technology platform. Over time, scientists would likely be able to more deeply calibrate their expectations for student work. However, understanding the context for high school students' work and managing expectations is liable to remain an issue in this model of expert involvement that leverages scientists with varying levels of experience in this kind of work at scale. Subsequent enactments of other units in the life sciences curriculum have made a first attempt to problem-solve how to bring scientists into a greater understanding of the contexts for learning, the lives of the students and calibrating expectations for student work by increasing synchronous interactions (e.g. chat, Skype and classroom visits), and having teachers and students provide more detailed background information on themselves and their school. Future efforts will also build

more extensive professional development for scientists into the experience that include examples of student work. Because this was a pilot study of the curriculum, we did not have these initial examples to share with the scientists. Providing scientists with a window into student life and work from a distance via a technology platform is a design issue that will need to be explored further.

### **Discussion: Proposed Features of Scientist-Teacher Collaboration**

The workings of scientific communities are diverse, being both discipline-specific and temporally dynamic. In order to maintain authenticity of science in science education, scientists from across these subcultures will necessarily have a role to play in helping those outside their community learn the variety of relevant scientific practices and processes necessary to become successful participants in science. Tackling difficult science education challenges requires effective collaborations between these natural scientists and teachers, learning scientists, technologists, educational assessment experts and students.

Climate science education is no exception to this need for partnerships, and there are particular dimensions to climate science learning that make interdisciplinary partnerships particularly necessary and appealing. First, this is a topic that, as discussed in Chapter 1 of this dissertation, has important societal implications; thus having a populace that is literate in climate science is important for addressing the human impacts of climate change. The collaborative work of those who deeply understand scientific and social issues, and the intersection of these issues will support students' engagement with this socially relevant topic. Secondly, climate science research relies on cutting-edge tools and technology that are rarely the focus of science curricula. Teachers and students alike

require support to proficiently participate in novel practices like climate modeling that will allow them to use these data appropriately to address climate-related problems in their own lives. This study highlights some of the challenges that scientific experts may have in supporting the teaching and learning of science, including difficulty anticipating learner challenges related to scientific practices, under-appreciating different dimensions of scientific expertise, and difficulty gauging the appropriate level of student performance. The following five strategies are suggested as ways to address challenges that may arise during scientist-educator and scientist-student interactions as these three groups cross boundaries between scientific and educational contexts.

#### 1. Understanding what it means to be a scientist and a science learner

As discussed in Chapter 3 of this dissertation, scientists in this study valued supporting learners' scientific process by providing access to authentic tools, technology and practices. From their own educational and scientific experiences, scientists see the value of creating educational experiences that not only rigorously address conceptual understandings, but also provide experiences that allow learners to act like scientists, taking on the processes and practices of scientists. However, as demonstrated in the above analysis, scientists may not have a fully realized idea of what is necessary for science learners to participate in scientific practices beyond the conceptual understanding. Bringing scientists into the literature on science learning to make clear the complexities involved in the teaching and learning of science is one strategy to help scientists participate more effectively in science education.

Allowing scientists time to reflect with those outside of the scientific community on

the values, norms, epistemologies and tools of their scientific cultural communities may also help scientists identify areas in which their day-to-day activities differ from those outside of the scientific community. While the focus of this dissertation has been on K-12 education, reflections of this kind may have value more generally for scientists' communication with the public writ large. For example, in Chapter 3, I show a discussion between scientists in which they distinguish between evidence valued within their community (data and graphs) and that valued by some of their students (personally relevant stories). Examining how their own values and preferred discourse styles may be in tension with those of other communities may help scientists broaden their communication toolboxes. Explicitly describing what it takes to participate effectively in science, will allow scientists to more comprehensively anticipate where challenges may be for learners, and to develop supports for those challenges.

## 2. Identifying own areas of scientific expertise

One challenge described in this study is that scientists had a tendency to under-appreciate dimensions of practice not related to content knowledge. Developing a greater understanding of dimensions of scientific learning, especially practices, by exploring case studies that highlight other strands of learning will help scientists have a broader picture of the potential expertise they have beyond content knowledge (i.e. exploring the six strands of science learning, NRC, 2007; 2009) It may be useful for scientists to work with educators or others outside of the scientific community to enumerate the expertise they have related to scientific practices and to distinguish how this expertise may be distinctive to the scientific community. For example, Scott could become more aware of his own expertise in

scientific argumentation, and work with those with pedagogical expertise to identify the important components of this expertise and understand how to support students in increasing their own proficiency in scientific argumentation.

One benefit of helping scientists identify their own expertise is that it may help scientists feel their contribution to an educational experience is more valuable. I followed up with Scott after reading his exit survey to discuss his contributions. This conversation was helpful for Scott, because it made him feel like his contribution had more value than he originally thought.

### 3. Guiding expectations for student performance

Teachers and learning scientists play an important role in helping scientists gauge the appropriateness of student work, develop reasonable expectations for student performance, and informing the teaching process. This is pertinent both to scientists involved in design work who may be unaware of classroom norms and constraints, relevant learning goals (relative to educational standards), learner characteristics, or the level of work expected at different grade levels. It is also important for scientists who will be interacting directly with students to be adequately prepared for the quality of work the students are expected, and what the students will likely find challenging. These expectations will vary across classrooms and curricula, and teachers have a crucial role to play in preparing scientists to give effective feedback. Providing examples of student work that does and does not meet the performance standard, providing clear guidelines for giving feedback and the priorities of the feedback, and providing as much information about classroom activities to the scientists as possible will help scientists more effectively

interact with students. In addition to these classroom and curriculum-specific ideas, learning scientists can provide access to research literature on learning that will help scientists evaluate student work in the context of consensus accounts and theories of learning.

#### 4. Leveraging the Expertise of All Participants

Research literature on partnerships advocates for partnerships that are mutually beneficial and leverage the expertise of all participants (e.g. Bell, 2004; Linn, Songer & Eylon, 1996; Linn, Shear, Bell & Slotta, 1999). Linn et al. (1999) point to the need to create “an environment of mutual respect” when supporting partnerships (p. 62). In Drayton and Falk’s (2006) examination of teacher-scientist interactions in an apprenticeship program, they concluded that the success of the partnerships hinged on an equal power dynamic between the scientist and teacher, where research questions, goals and activities were co-constructed. Negotiation of goals for the program between scientists and teachers allowed the teachers to take ownership of their experience, pursue activities that were meaningful to them and fulfill their own goals. When the goals of the experience were not aligned between scientists and teachers, or where there was a conflict of personality, the participants viewed the experience as less successful. Similarly, this study reinforces the importance of recognizing and leveraging the expertise, values and goals of all participants in these interactions.

As described in Chapter 3 of this dissertation, scientists have educational experiences as teachers and students that, along with their participation in scientific communities, inform their participation in educational contexts. However, as this and

other studies show (e.g. Nathan, Alibali & Koedinger, 2001; Shulman, 1986) scientists may have trouble anticipating high-challenge areas if they do not also have expertise in education and learning. Fortunately, teachers, educators, and learning scientists have this pedagogical expertise, and also have a deep knowledge of the opportunities and constraints of their own districts, schools and classrooms. In scientist-educator interactions, it is important that it is not just the scientist who is the “expert.” Teachers have an equally valuable expertise to share with the scientists that is necessary for effectively supporting K-12 learners. In this study, teachers often used a lens of student understanding as they learned new material. That is, they were concerned with how their students would understand material, and were able to locate challenging or interesting areas, and ask questions they were likely to be asked in the classroom. This perspective was necessary for developing activities that would be successful in a classroom.

In addition to recognizing the expertise of scientists and teachers, it is also essential not to overlook the expertise of students. Student voice is essential for helping discern what aspects of curricula are challenging, interesting and relevant to students. Students are also experts in their own learning, and have insight into what types of learning experiences they enjoy and benefit from. After all, as discussed in Chapter 3, it was a high school student who planted the seed of moving the Dual Credit Climate Course from a PowerPoint format to one that was more active. Attending to learners’ needs and interests is essential for supporting their participation in scientific practices.

##### 5. Creating opportunities for all participants to give and receive feedback

Just as it is important to recognize expertise, it is also necessary to provide

opportunities for open communication between scientists, educators and students. This allows, for as Linn et al. (1999) describe “ongoing professional development for *all participants*” (p. 76, emphasis in original), as participants share experiences and learn through collaboration. By listening to the teachers in the pilot study, the scientists learned about what was challenging for the teachers and what would likely be challenging for students. They uncovered areas where varying social norms caused conflict, and developed their own pedagogical expertise. In professional development workshops that followed the ones discussed here, scientists were better equipped to anticipate challenges the teachers might face, and to support teachers’ use of technology such as Excel.

Just as scientists provide feedback on student work, it is also important that scientists receive feedback from educators and students as to how they can best support student learning. This feedback will help scientists establish realistic expectations for student work, and will also help them determine what kinds of feedback are most useful to learners at various levels of proficiency in scientific practices. Establishing collaborative, constructive communication across scientists, teachers and students will aid scientists as they work to contribute to science education.

## **Conclusion**

Scientific work is complex. To successfully participate in scientific arenas requires multi-faceted expertise that encompasses conceptual, epistemic, social and technological dimensions. The teaching and learning of these scientific practices is similarly complex, encompassing a diversity of learners with varied purposes for scientific understanding in

society. Scientists seeking to support learners' participation in scientific practices need to consider challenges that may arise for learners across all four of these dimensions: social, epistemic, conceptual and technological. Experts may struggle to identify and address these challenges, and may need support and feedback from teachers with pedagogical content knowledge, and students who can describe their own learning challenges, to effectively bring new participants into these complex scientific practices. Further research should more fully explore the proposed strategies for scientist-educator and scientist-student interactions, and explore other possible opportunities, challenges and strategies for involving scientists in education.

Supporting climate scientists' involvement in climate change education will only become more necessary as we seek to foster a generation of citizens prepared to meet the challenge of a changing climate and shifting resource availability. Responding to climate change will require science learners who are proficient in using scientific work in their decision-making processes. Scientists and science learners will need to support each other in order to communicate effectively and problem-solve scientific issues using scientific evidence instead of only political ideology. This communication requires attending not only to the well-known issues of language, vocabulary and jargon, but also to the underlying cultural, social and epistemological norms that guide scientific work, and that undergird the evidence that science produces.

Teaching in a field as interdisciplinary and new as climate science can be a daunting task for teachers. As a community, we are asking teachers to take on the responsibility of preparing this new generation to address issues related to climate change, even as the

teachers themselves are learning the science. In this study, teachers found it especially difficult to engage with the epistemological dimensions of climate change science, that is, the unique ways that climate scientists used tools like climate models to construct scientific knowledge. It is important that we support teachers in these dimensions climate science that are necessary to understand in order to appropriately use scientific evidence to address the societal impacts of climate changes. Teachers will need support from the scientific and educational research communities to rise to the challenge of preparing the next generation to address the impacts of a changing climate. By leveraging the consensus knowledge base about the science of learning science, we can help teachers support learners in their participation in socially consequential and personally relevant science.

The responsibility of improving science education on socially relevant issues should not rest solely on the educational community to teach the public, the scientific community to develop new and better ways of communicating their science, or citizens to increase their facility with scientific evidence. These three groups and three aims are intertwined; by supporting one group, we will support them all.

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**APPENDIX A: HIGH SCHOOL CLIMATE COURSE INTERVIEW PROTOCOL (SCIENTIST)**

Initial Interview:

*Obtain verbal consent for video-taping.*

*Thanks for agreeing to this interview. As we go through, let me know if you want to skip a question and we'll move on to the next one.*

Background and current research

- How did you become interested in climate science?
- What is your current research project or field of study? (*i.e.* What are you currently working on?)

Involvement with the curriculum development project

- What motivated you to get involved with this project?
- What piece of the project are you working on?
- Why did you decide to work on that piece?

Involvement in outreach and education in general

- Have you done outreach in the past?
- Do you have a prior history of other kinds of educational work?
- How did you get involved in outreach/education?
- What do you like about it? What is rewarding? What is difficult? What do you dislike?

Supports and challenges for scientists in outreach

- What are some characteristics of successful science communication?
- What resources—books, people, programs, etc. help you when you are doing outreach? Can you give an example?
- What do you think are the biggest challenges for scientists who want to do outreach? Who or what helps you address these challenges?
- Are there any resources or challenges that you think are particularly related to climate science?
- Do you/how do you see yourself being involved in education in the future?

**APPENDIX B: HIGH SCHOOL CLIMATE COURSE INTERVIEW PROTOCOL (TEACHER)**

## High School Teacher Initial Interview Protocol

*Obtain verbal consent for video-taping.*

*Thanks for agreeing to this interview. As we go through, let me know if you want to skip a question and we'll move on to the next one.*

## Current Teaching

- Tell me a little bit about the classes you currently teach.
- What are your favorite things about your students? What's challenging?
- What are some resources -- books, people, programs, etc.-- or strategies that you use to help students learn science? Why are these useful? What do you not have?

## The Curriculum Development Project

- How did you get involved in this project? What attracted you to it?
- What are your goals for the workshop going in? (Are there goals for yourself, for your students?)
- What would you like this curriculum to look like ideally?
- How are you planning on using the curriculum in your classroom?

## Working with scientists

- What's your background in science?
- Have you worked before with scientists on a project like this?
- What is useful about working directly with scientists? What is challenging?
- If you could give advice to the scientists about how to communicate effectively with educators, specifically, or the public in general, what would that be?

**APPENDIX C: HIGH SCHOOL CLIMATE COURSE DAILY EXIT SURVEY**

Climate Science Teacher Workshop

[Date]

**Please fill this out before you leave!! Thanks!**

Name (optional):

I am a (circle):      graduate student      HS teacher      UW faculty/staff      other:\_\_\_\_\_

1. I learned a lot in the workshop today.

*Strongly Agree   Agree   Somewhat Agree   Somewhat Disagree   Disagree   Strongly Disagree*

2. I greatly enjoyed the interactions I had with scientists, educators and others today:

*Strongly Agree   Agree   Somewhat Agree   Somewhat Disagree   Disagree   Strongly Disagree*3. What was one thing that was *interesting or enjoyable* today and why?4. What was one thing that was *frustrating or challenging* and why?

5. One thing I learned today is...

6. One question I have is...

**APPENDIX D: ECO. IMPACTS OF CLIMATE CHANGE INTERVIEW PROTOCOL SPRING  
2011 (SCIENTIST)**

- What is your current position?
- How long have you been in your current position?
- Describe a usual day in your work.
- How did you become trained in this field? Undergraduate degree? Graduate school? Professional training?
- Have you done public and/or educational outreach in the past? If so, tell us about it.
  - What do you like about doing educational work? What don't you like?
- Why did you agree to participate in this project?
- What was your role in this project?
- What did you like about it? What was rewarding? What was difficult? What did you dislike?
  - Technology versus face-to-face
- How long did it take you to do the feedback?
  - How much time would you be willing to spend on a project like this?
  - How much lead time do you think you need to give feedback (couple days, a week)?
- Are there other supports we can put in place to help you?
- What suggestions do you have for us with respect to your involvement in the module/unit?
- How can we get other experts involved?
- What do you think are the biggest challenges for experts (e.g., scientists, writers) who want to do outreach? Who or what helps you address these challenges?
- What are some characteristics of successful science communication or teaching?
  - K12, grad school, informal
- What resources—books, people, programs, etc. help you when you are doing outreach? Can you give an example?
- Do you/how do you see yourself being involved in education in the future?

**APPENDIX E: ECO. IMPACTS OF CLIMATE CHANGE EXIT SURVEY FALL 2011  
(SCIENTIST)**

Question 1.

Name:

Question 2.

What is your current position?

Question 3.


How long have you been in your current position?

Question 4.

What kinds of educational work have you done in the past (can include teaching at any level, outreach, etc.)? Please include both the type of work and level (e.g., high school, middle school, adults).

Question 5.

How did you participate as an Educurious expert?

- Skype with class
- Gave feedback on student work
- Corresponded with students via messages on platform
- Visited the classroom
-   Other:

Question 6.

If you interacted with the students in more than one way (e.g. Skype and gave feedback), which did you prefer and why?

Question 7.

What did you like, or what was rewarding, about your involvement in this unit?

Question 8.

What didn't you like, or what was challenging, about your involvement in this unit?

Question 9.

Is there anything that the Educurious team could do to better support experts who are involved in this and similar units? That is, how could we have made your life easier?

Question 10.

What other suggestions or comments do you have for the Educurious team with respect to your involvement in the unit?

## APPENDIX F: ECO. IMPACTS OF CLIMATE CHANGE INTERVIEW PROTOCOL (STUDENT)

Now that you've been students in the unit for the past few weeks, you're in a unique position to help us make the unit even better in the future. We are interested in figuring out what kinds of things could we change to make it more successful? We want to know what things worked for you, what pieces of the curriculum you found engaging and valuable and in what ways could we change things to make this experience better for you? We would like to use this focus group time to learn more about your experiences with the curriculum, the platform, the videos, the staff, and the experts.

- **Curriculum pieces**
  - What was your favorite part of the module?
  - What was challenging about the module?
  - What would you change about the module?
  - What types of activities do you think should be included in the module/unit?
    - What pieces do you think are missing and/or could be improved?
  - What essential aspects would you like us to keep in mind as we redesign the module?
  - What did you learn in the module? OR What do you feel like you learned?
  - How did you learn best in the unit?
- **Climate Specific Questions (particular for each group)**
  - Ask them about their answer to the 6 Americas question on the post-test.
  - Do you think your answer has changed over the course of the module? Talk more about that (why or why not).
  - Where had you heard about climate change before this unit started (media, family, friends, other)?
  - What has influenced your ideas about climate change? Family? Friends? Political affiliation? Media? Religion?
  - Discuss some specific instances in class (for particular students; e.g. the talk with Madeleine)
  - To all: If you are taking action, what are you doing? If you aren't, why aren't you?
  -
- **Experts**
  - What were your experiences like interacting with experts?
  - Was the feedback that the experts provided for you useful? If so, what was useful about it? If not, why not?
  - What advice do you have for experts to make their feedback more helpful to you?
  - Did you enjoy collaborating with professionals/experts? If so, what were your favorite types of interactions (e.g., through the platform, in person, over Skype)?

- **Platform**
  - What did you think about the social networking platform
  - What features could be added to the platform to make it more collaborative? Useful.
  
- **Resources/videos**
  - How did you like using Fieldscope? What was challenging/useful?
  - Are there any technologies that you use regularly that we should incorporate into the unit OR final project?
  - Which videos did you like? Which ones did you find most interesting? Least interesting? (prompt with screenshots)
  - Was there anything you learned from the videos that you used or thought was valuable/interesting?
  - Are there things we could have done to make the videos better?
  
- **Final Projects/ Challenge**
  - Did you feel the instructions/ guidelines for the final project were clear and easy to follow?
  - Did the assignments/ exercises in the unit prepare you to do the final project/ meet the expert challenge?
  - Were there other resources that prepared you?
  - What else would have prepared you?
  - Did you have enough time to work on the final project?
  - What did you like about the final project?
  - What was difficult about the final project?

**APPENDIX G: ECO. IMPACTS OF CLIMATE CHANGE INTERVIEW PROTOCOL  
(TEACHER)**

- What were your expectations of this experience before the project started?
- Now that you have been involved, what are your expectations?
- With respect to the various types of professional development you are offered, what seems most useful at this point and why? What seems least useful and why? How could those experiences in your 'least useful' category be more useful?
- What other types of professional development opportunities would you like access to?
- What are your perceptions of project-based learning?
- What do you find most difficult about implementing project-based learning as an instructional strategy?
- In your professional opinion, do you think project-based learning facilitates student learning?
- What questions (new questions) do you have about project-based learning?
- How did the curriculum enactment go?
- What worked well? Why?
- What didn't work well? Why?
- What did your students like?
- What didn't your students like?
- What were the challenges in teaching the module/unit?
- How can we revise the module/unit?
- How were the interactions with the experts? Were they useful? Not useful? Why or why not?
- How were the experiences with technology? What worked well? What did not work well? Why or why not?

## APPENDIX H: ECO. IMPACTS OF CLIMATE CHANGE WEEKLY ENGAGEMENT SURVEY (STUDENT)

### Question 1.

What is your name?

### Question 2.

Teacher's Name

### Question 3.

Class Period

### Question 4.

Please answer the following questions based on your experiences this week.

Required.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
I had fun working on the climate change activities this week.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I was absorbed in what I was doing while I worked on these activities this week.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Time seemed to go by very quickly while I was working on the climate change unit.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The interactions with other people (group, experts, educators) were very enjoyable this week.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I was able to participate in and contribute to our study of climate change this week.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would like to learn more about climate change or this kind of scientific work (e.g., fieldwork, climate modeling, lab experiments, etc.).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

### Question 5.

What is the most important thing we can do to improve the climate change unit?

## APPENDIX I: ECO. IMPACTS OF CLIMATE CHANGE POST ASSESSMENT (STUDENT)

**Full Name**

**Teacher's Name**

**School name**

**Class period**

1.  
What is climate?

2.  
What is weather?

**Do the following scenarios have to do with climate or weather?**

3a.  
The mayor of Seattle decides to build a fleet of snow plows.

- Climate  
 Weather

Why?

3b.  
It snowed 10 inches in the mountains last weekend.

- Climate  
 Weather

Why?

---

Sam set up a plant experiment with two plants. She controlled the number of seeds planted, and the amount of fertilizer, sunlight and soil. She always kept the soil damp for each plant. She put one plant under a heat lamp for 6 hours a day. The other plant was NOT put under a heat lamp at all.



*Plant without  
heat lamp*

*Plant put under heat lamp  
for 6 hours a day*

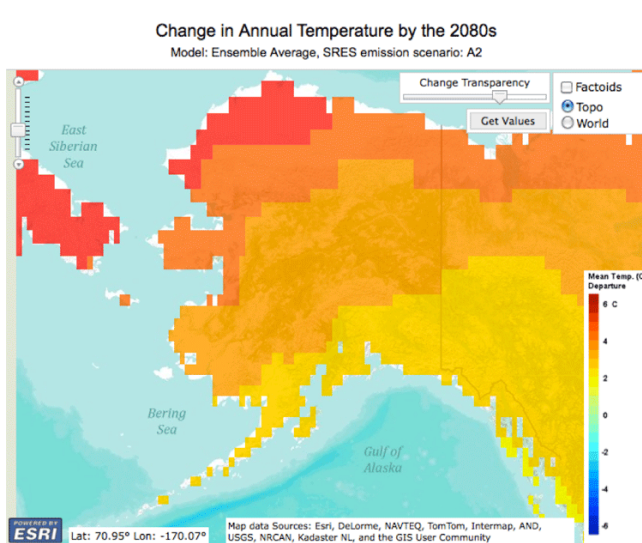
**Plant Height and other observations**

Time	Plant #1: light only (no heat)	Plant #2 placed under heat lamp for 6 hrs a day
Day 4	2 cm tall	3 cm tall
Day 7	3 cm tall	5 cm tall
Day 10	6 cm tall	9 cm tall; flower buds
Day 13	13 cm tall; flower buds	19 cm tall; flowers blooming
Day 16	16 cm tall; flower buds	21 cm tall; flowers blooming
Day 19	18 cm tall; flowers blooming	22 cm tall; flower pedals falling off
Day 22	20 cm tall; flowers blooming	23 cm tall; no flowers left

4a.  
What differences do you see between the two plants?

4b.  
What can you conclude from the results?

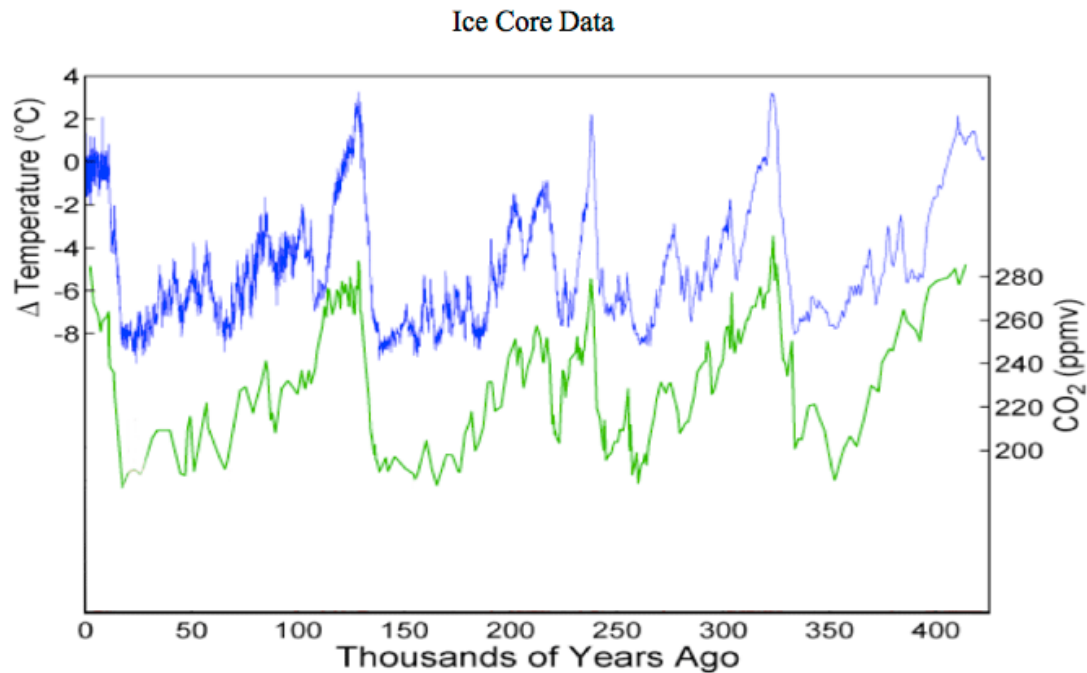
4c.  
How is this plant experiment related to climate change?



5a.  
In the picture above, what does the RED represent?

5b.  
The picture above shows a model of predicted temperature changes in Alaska because of climate change. Based on this graph, how will temperature change in Alaska by the 2080s? Describe as many changes as you can.

5c.  
Imagine there is a certain kind of flower that only lives in the middle of Alaska. What are two changes might happen to this flower between now and 2080 based on the temperature changes you described above?



Scientists use ice cores to find out about past temperature and carbon dioxide in the atmosphere over the past 400,000 years. The above graph shows change in temperature (written as  $\Delta$ Temperature on the left-hand y-axis) and CO<sub>2</sub> in the atmosphere (on the right-hand y-axis) over the past 400,000 years. Use the graph above to help you answer the following questions.

6a.

What is the highest amount of CO<sub>2</sub> measured from ice core data in the past 400 thousand years?

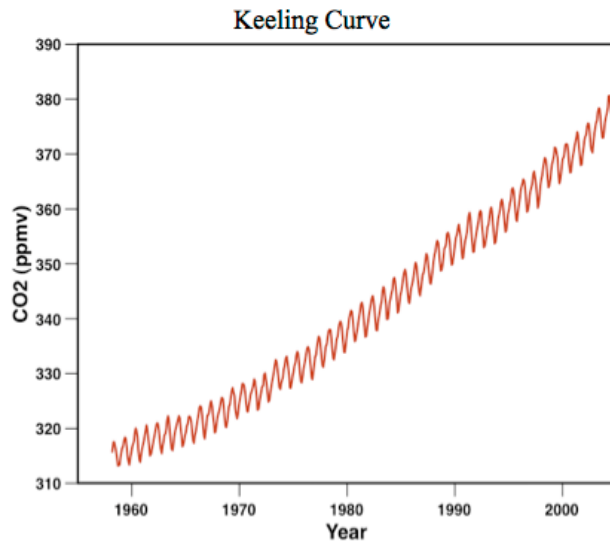
6b.

What is the lowest amount of CO<sub>2</sub> measured from ice core data in the past 400 thousand years?

6c.

When levels of CO<sub>2</sub> increase, temperature:

- a.) increases
- b.) decreases
- c.) stays the same



6d.

What are some similarities between the Keeling curve and the ice core data?

6e.

What are some differences between the Keeling curve and the ice core data?

7.

Scenario: You just watched a YouTube video of someone talking about how climate change is NOT happening. The person said that the change in climate is due to natural variation in temperatures that we have always seen over the course of time. How would you respond to the person's argument that the climate change is part of the Earth's natural variation in temperature?

---

8.

How sure are you that climate change is currently happening?

- Extremely sure it IS NOT happening 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- Extremely sure it IS happening 10

9a.


How serious of a problem do you think climate change is?

- Not a serious problem at all 1
- 2
- 3


- 4
- Extremely serious problem - 5

9b. Why?

10. Assuming climate change is currently happening, do you think it is...

- Caused mostly by human activities
- Caused mostly by natural changes in the environment
- None of the above because climate change isn't happening
- Don't know
-   Other:

11. Please pick which one most describes you:

- I am already taking action to respond to climate change and I think it's important
- I think climate change is important but I'm not taking action yet
- I don't think climate change is important and I am not taking action
-   Other:

12a. Do you think the way you feel about climate change has changed over the course of the unit?

- Yes
- No
- 
- 

12b. Why or why not?

## APPENDIX J: INFOGRAPHIC FEEDBACK, FROM SCOTT TO WALT

Overall this is a fantastic start. Visually the poster is appealing, the scientific information is well researched, and the topic is important. Your main focus now should be to make it clear how and why forests are affected by climate change, list out why people should care about this, and just connect the dots between cars and trees (see my comments below). I really look forward to seeing the final product on this.

- The "vehicles per 1000 people" and "global carbon emissions" graphs demonstrate that people are contributing to pollution with carbon dioxide emissions. This is a nice set of graphs to show how driving is connected to petroleum (gas) use.
- "Clean air at Niwot Ridge" - This is great evidence that we are adding carbon dioxide to the atmosphere from fossil fuels - It is great that you have that graph coming from the tailpipe of the car! This graph actually conveys a pretty complicated message, but your summary is pretty accurate! If you didn't talk about this graphic in class, it might be good to choose another one (i.e. Keeling Curve) since this might be difficult for your classmates to understand (even though your caption is great).
- The graphic in the upper right and left corner is a great illustration of the greenhouse effect! The explanation is awesome. The "Reflected photons" aren't actually "reflected" but are "re-emitted" (and in all directions, not just down). Really great job here! I am impressed by the explanation.
- It might be helpful to include the temperature graph over time to show that temperature has increased this past century (to add to your greenhouse effect figures). You have a great *theoretical* explanation (i.e. why it warms), but didn't actually show that it warms (most people know this, so if you don't include a graph of temperature change it isn't too big of a deal).
- There is a good connection for:  
People drive cars → petroleum is used → more CO<sub>2</sub> → larger greenhouse effect → Earth is hotter → trees die off (this last step needs more information - either a text explanation, a picture with text, or a figure)
- Maybe you could make this logic clear with arrows from cars to petroleum use to increased CO<sub>2</sub> to a warmer Earth to dying trees) somehow. You could also include a text explanation that walks other students through this logic.
- Is there any information about why forests will die off? Is it just too hot for any trees? Will some trees survive? Are there other species (i.e. mountain pine beetle) that play a role here? Is there any place where trees can survive (on mountains? near the north or south pole?)?
- It might be good to incorporate your main concern (forests?) in the title or in large font somewhere (maybe you could include a picture, too).
- I love the Earth decals on the car!
- The illustration of cars knocking over trees with too much CO<sub>2</sub> is great! It really illustrates your point that cars and carbon dioxide are hurting forests in a visual way.
- So far this is great! It would be really nice to try to work on the connection between increasing temperatures and forests dying off. It's okay if you don't know the exact

impact, but you want to convey that forests are threatened and will be harmed by global warming.

- I think it is obvious why we should care about forests, but maybe you could list some examples for your classmates. Would killing forests actually make global warming worse since CO<sub>2</sub> would be absorbed by fewer plants (and so the greenhouse effect might be larger)?
- I really like that you chose to research forests in global climate change. Forests are so important for many species and are so large that they can affect rainfall and temperature in different regions of the Earth. You are off to a fantastic start on your poster and I love the graphics you have picked out. Really good, creative work! Thank you for that.

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University of Washington

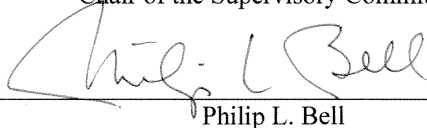
Graduate School

This is to certify that I have examined this copy of a doctoral dissertation by

Elizabeth M. Walsh

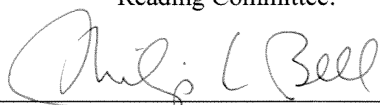
and have found that it is complete and satisfactory in all respects,  
and that any and all revisions required by the final  
examining committee have been made.

Chair of the Supervisory Committee:

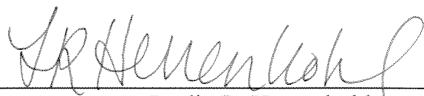


Philip L. Bell

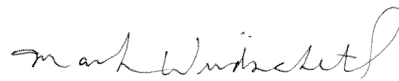
Reading Committee:



Philip L. Bell



Leslie R. Herrenkohl



Mark A. Windschitl

Date: May 30, 2012

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## VITA

Elizabeth “Elly” Walsh began her graduate career in the School of Oceanography at the University of Washington in 2004, earning a M.S. Chemical Oceanography in 2006. She continued her doctoral work in oceanography studying past climate changes, but eventually realized she was too intrigued by the social context of climate change and the learning of climate science to continue as an oceanographer. She transferred to the College of Education where she earned a Doctor of Philosophy in Learning Sciences at the University of Washington in 2012. Elly is originally from San Francisco, and after earning her degree returned to the Bay Area as Assistant Professor of Climate Science and Science Education at San Jose State University.