Supporting and Understanding Students' Epistemological Discourse About Climate Change

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Supporting and Understanding Students' Epistemological Discourse About Climate Change

Nicole Holthuis,[1,a] Rachel Lotan,[1] Jennifer Saltzman,[2] Mike Mastrandrea,[3] and Andrew Wild[4]

ABSTRACT

The climate change community has begun to look carefully at how the public understands, or fails to understand, climate change and the scientific claims made based on data. This study focuses on how teachers provide scaffolding that supports students' understanding of, not only how climate systems work or the causes and effects of climate change, but also how we know what we know. Stanford's *Global Climate Change: Professional Development for K–12 Teachers* project provided teacher professional development on the science of global climate change, curricular materials, and pedagogical strategies. We conducted an in-depth study of the classrooms of the participating teachers. Our results show statistically significant gains from pre- to postassessment in students' content knowledge and a shift in their opinions about climate change. These gains are positively related to the percentage of students who are engaged and interacting, and negatively related to the percentage of students who are disengaged. Through classroom observations and video recordings, we identify how teachers and students talk about how we know about climate change, and we discuss how that talk can be enhanced. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-036.1]

Key words: climate change education, argumentation, scientific practices, student interaction

INTRODUCTION

The climate change community has begun to look carefully at how the public understands, or fails to understand, climate change and the scientific claims made based on data. Researchers have found that a deficit model of knowledge doesn't fully explain why people continue to disagree about the reasons and the processes of climate change. As Bowen and Rodger (2008) argue, understanding climate change "hinges less on lack of understanding of climatologists' claims regarding global warming, and more on the lack of an appropriate interpretive framework for making sense of the knowledge held" (p. 97). In other words, even if an individual knows the content of climate science, the processes that scientists have gone through to make their claims are not fully understood and acknowledged. Deniers do not become acceptors simply by filling up their cognitive data banks with content knowledge.

This suggests that teachers need to provide scaffolding that supports not only students' understanding of how climate systems work or the causes and effects of climate change, but also how we know what we know. What is the evidence for anthropogenic climate change? What data are missing or are currently being collected? How confident are scientists about their claims? What claim can be made from a particular set of data? And conversely, what claim cannot be made given these data? Climate change education provides not only an excellent opportunity to integrate science content with scientific practices, but also an imperative to do so.

There are many ways to provide students with opportunities to gain an epistemic understanding of climate change. Students may look at the tools and methods climate scientists use as they collect and analyze ice cores. They may explore how our understanding of climate has changed over time from Arrhenius to today. Or, as we explore here, they may engage collectively in the process of argumentation in which they arrive at a conclusion or claim supported by evidence. We take the position that learning to construct and evaluate arguments involves growth in scientific practices *and* metaprocedural (epistemic) knowledge. However, opportunities for students to participate in authentic scientific argumentation in the classroom are rare (Weiss et al., 2001; Roth et al., 2006). Efforts to include scientific argumentation in the context of climate change education have only just begun. In this study, we focus on the following research questions:

1. What did students learn about climate change and to what extent have their opinions shifted after experiencing a climate change curriculum?
2. How do teachers and students talk about how we know about climate change?
3. What classroom conditions support such talk?

THE STANFORD PROJECT

Our team of climate scientists and science educators embarked on a 3-year project entitled *The Science and Policy of Global Climate Change: Professional Development for K–12 Teachers*. This NASA-funded project was designed to enhance students' knowledge of climate change as well as their awareness of mitigation and adaptation strategies that address the effects of climate change.

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The major goals of this unique interdisciplinary collaboration between Stanford's Graduate School of Education and the School of Earth Sciences were: (1) to provide intensive and extensive professional development opportunities for teachers to gain deeper knowledge and understanding of the scientific principles and evidence for global climate change and to strengthen their confidence in addressing related policies; (2) to enhance teachers' pedagogical skills and use of appropriate curricular materials to support student learning; (3) to develop and disseminate middle- and high-school curricular materials; (4) to support sustained implementation of global climate change topics in the participating schools' curricula; and (5) to document student learning about the science and policy of global climate change.

In this paper, we report on our research in the second year of our 2-year data collection. The focus of this research grew out of our findings from classroom observations and student assessment data in the first year. We found that students demonstrated significant learning gains as measured by pre- and posttests (Holthuis et al., 2012). In addition, we observed high levels of student engagement and interaction that were related positively to student achievement. However, as we looked at teachers' classroom talk, we found a majority (58%) of the teachers' talk was factual content and procedural while much less of their talk fell into categories more specific to scientific analysis, application, and interpretation. Yet, this latter type of talk is consequential. We found that it was positively and significantly related to overall level of student engagement and interaction.

Looking more closely at the posttests, one student's response prompted extended discussions for the research team. Students were asked whether or not a freak snowstorm in Arizona—the first storm in 100 years—is evidence that global warming is *not* happening. A 6th grader wrote: "No, a snowstorm is weather, global warming is about the climate, which is different." And then the student continued: "But I still don't think it's happening either."

This student's response suggests that he or she distinguished between weather and climate, and is perhaps correctly implying that one single event is not evidence to support or refute the claim of climate change. And yet, this student could still be labeled a "denier." How many other students, we wondered, gained some understanding of climate science and climate change and yet still thought that climate change wasn't actually happening? And why? With this in mind, we turned our attention to how students come to understand how we know what we know—a topic that the science education community has been grappling with for some time.

CONCEPTUAL FRAMEWORK

> *It is ironic that science, which presents itself as the epitome of rationality, so singularly fails to educate its students about the epistemic basis of belief, relying instead on authoritative modes of discourse . . . that leave students with naïve images of science . . . and little justification for the knowledge they have acquired.* (Osborne et al., 2004, p. 996)

Talking to Learn

Many science educators have placed great importance on the role of discourse and discussion in science classrooms over the last two decades. They seem to agree that students should be "talking science" (or at least school science) as a means of not only appropriating the particular register, or dialect, but also as means toward conceptual understanding and meaning-making (Mortimer and Scott, 2003). Essentially, this is a shift in emphasis from talk as an instrument of teaching to talk as a conduit to learning.

This movement toward discussion and focus on discourse was driven initially by constructivist theories of learning and knowledge. The construction of knowledge is seen as a social process and stresses the fundamental role of discourse and dialogue in shaping meanings (Wertsch and Toma, 1995). According to Vygotsky (1978), "learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers" (p. 90). Student talk is thus seen as a way of sorting out one's thoughts about tasks, situations, problems, and puzzlements.

Using Vygotsky's notion of social construction, Driver et al. (1994) argue that learning science is a process of enculturation. In this sense, observing and manipulating materials and equipment are necessary, but not sufficient components of constructivist teaching practices. Discourse and analytic reasoning are needed. In other words, they argue, students in a science classroom or setting must be provided more than just experiences; they must be given ample opportunities to have authentic, open-ended discussions with each other and the teacher.

Similarly, Roth and Lee (2002) speak of science literacy in a broad sense as an emergent feature of collective human practice, an endeavor in collective knowledge making requiring participants at all levels be engaged in an ongoing conversation. As such, science literacy—and climate literacy more specifically—is a collective phenomenon rather than an individual one, requiring educators to engage students in discourse about pertinent climate science-related issues, grounding their learning experience in the real world. These sentiments are echoed in many recent research and policy documents written by the National Research Council. For example, Michaels et al. (2008) state:

> *In order to process, make sense of, and learn from their ideas, observations, and experiences, students must talk about them. Talk, in general is an important and integral part of learning, and students should have regular opportunities to talk through their ideas, collectively in all subjects areas. Talk forces students to think about and articulate their ideas.* (p. 88)

A growing body of empirical evidence supports this emphasis on the value of teacher-to-student and student-to-student interaction and its relationship to learning. Researchers are gaining an understanding of whether and how this talk actually leads to a conceptual understanding of science concepts.

Numerous studies were conducted based on sociological perspectives on classrooms at the Program for Complex Instruction at Stanford University. Evidence gathered in elementary, middle, and high schools across different subject

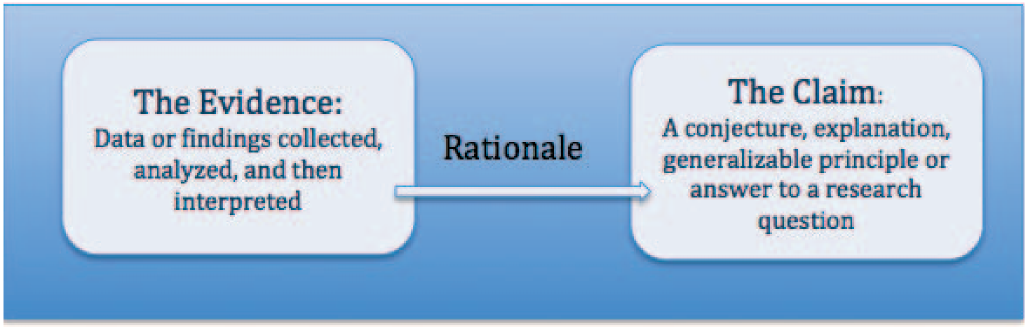

FIGURE 1: Basic elements of a scientific argument.

areas showed that, given appropriately crafted learning tasks, at the classroom level the average proportion of students interacting on-task was positively related to average learning gains on various measures of achievement (Cohen et al., 1989; Cohen et al., 1997). In other words, the more students talked and worked together, the more they learned. Echoing this finding, Bianchini (1997) showed a positive correlation between an individual's average rate of talk and his or her learning gains in middle school science classes. More recently, there have been studies that have measured learning by analyzing students' science talk over time (see, for example, Mortimer and Scott, 2003). In addition, as described below, our research in Year 1 confirmed that the level of classroom interaction is positively correlated to learning gains (Holthuis et al., 2012).

This emphasis on the role of discourse and interaction in science classroom assumes a sufficiently rich and demanding area of study. That is, discourse and interaction are *most* vital when students are grappling with difficult conceptual issues, theoretical models, or critical analyses—areas in which there are wide and/or significant gaps between everyday views and scientific understandings. The study of climate change and climate systems is precisely that. Thus, the nature of our understanding of the world's climate—what we know and how we know it—provides both an opportunity and an obligation for such discourse and interaction.

Learning to Talk

Given the emphasis on the power of talk as a conduit toward understanding, how can such interaction be facilitated and cultivated in the context of climate change education? More specifically, how can we support both teachers and students as they appropriate not just a new vocabulary, but a new way of talking about how we know, based on the epistemological underpinnings of climate science?

As described above, from research in science education we learn that students and teachers need to be enculturated into the ways of making sense as climate scientists do. Like these scientists, teachers and students need opportunities to talk, to think, and to act as members of a scientific community. This process is less about the acquisition of specific facts and procedures or even the refinement of a mental model, but is "a socially and culturally produced way of thinking and knowing, with its own ways of talking, reasoning, and acting, its own norms, beliefs, and values, its own institutions, its shared history, and even its shared mythologies" (Rosebery, 1992, p. 3). In this sense, science talk may be considered a register, much in the way that Halliday (1975) and Pimm (1987) define mathematical talk, or as a heteroglossia (Lemke, 1995).

One central component of this specialized language of science is scientific argumentation (Driver et al., 2000; Duschl, 2008). According to Duschl, argumentation "embodies the dialogic knowledge-building processes that are at the core of science, namely, obtaining and using principles and evidence to develop explanations and predictions that represent our best-reasoned beliefs about the world" (p. 269). It is a process whereby scientists must not only make inferences from data but they must be able to put their inferences, or theories, to the test. They must be able to both ask and answer the question: *How do you know?* He argues that the process of argumentation leads to solid epistemic understanding of science:

> *What research suggests is the proper game for understanding the nature and development of scientific knowledge is engagement with the ongoing pursuit and refinement of methods, evidence, and explanations and the subsequent handling of anomalies that are a critical component of proposing and evaluating scientific models and theories. In other words, dialogical processes characterize science-in-the-making approaches and the epistemic and social dynamics that seek to fill in the details between the initial and important context of generation scientific activities and the concluding and necessary context of justification activities.* (p. 286)

For the purposes of our work as curriculum developers, professional developers, and researchers, we used the following model to describe the components of a scientific argument (Fig. 1). A basic argument consists of a claim supported by evidence, and coordinated with a rationale. Often times, the rationale is implicit.

To learn and internalize this discourse of science, teachers need to provide structured opportunities for student to practice participating in scientific argumentation (McNeil and Pimentel, 2009). Through his research, Bandura (1969) established that children learn and imitate behaviors that they have observed other people demonstrate, display, or act out. According to Bandura, "One of the fundamental means by which new modes of behavior are acquired and existing patterns are modified entails modeling and vicarious processing" (p. 118). In particular, Bandura suggests that such modeling is an indispensable aspect of learning when the behavior sought involves intricate patterns; such as in the case of teaching the verbal responses that constitute a language. In addition, these new behaviors should not only be modeled but labeled and discussed as well. Hodson (2009) applied this same idea to learning the discourse of science: "There needs to be much more metatalk (talk about language), with teachers explaining why they are adopting a particular linguistic form. Students need to know that while everyday language will suffice on some occasions, a specialized language of science is necessary on others" (p. 250). Thus, learning how to talk about how we know requires that such talk be modeled, labeled and discussed, and practiced by both teachers and students. Below we consider how each of these three processes occurred in some of the climate change classrooms of our study.

SETTING, SAMPLE, AND METHODS

Eight high school teachers and ten middle school teachers from fourteen schools participated in this project during the 2011–2012 school year. We were able to obtain the following demographic data on twelve of the schools: race/ethnicity, designated English Language Learners (ELLs), students receiving free or reduced lunch (as a proxy for socioeconomic status), and the percentage of students who scored proficient or above on the California State Test in Science.

The distribution of girls and boys was reflective of the general population. The schools had varying demographic profiles in terms of the students' demographic backgrounds. Four schools had a majority (55%–58%) of Hispanic/Latino students, three schools had a majority (53%–71%) white, one had a majority (72%) Asian, and the other four schools had no one race or ethnicity in the majority. The percentage of students designated English Language Learners at each school ranged from a low of 2% to a high of 48%. Three of the schools had fewer than 10% ELLs, six schools had between 10% and 29%, three schools had 30% or greater. The number of students qualifying for free or reduced-price lunch varied from a low of 2% to a high of 71%. Six schools had up to 19% of their students qualifying, two schools had between 20% and 39%, one school had between 40% and 59%, and three schools had above 60%. The percentage of students who scored at or above proficient on the California State Test in Science varied with a low of 30% at one school to a high of 94% at another. Three schools had between 30% and 49% of students at or above proficient, three schools had between 50% and 69% at or above proficient, four schools had between 70% and 89%, and two schools had 90% or more.

The teachers participating in the professional development and research were representative of the population in the Bay Area. They varied in their prior knowledge about climate change as indicated in their application questionnaire. Their teaching experience ranged from one year to more than 20 years experience. Each of the teachers taught courses in science including Earth science, biology, chemistry, and/or environmental education.

These teachers attended a four-day, intensive summer workshop at Stanford University and two follow-up days during the academic year. Educators and climate scientists led the workshops in which teachers learned about and discussed the science of climate change, the most recent research in the field, and issues surrounding adaptation and mitigation strategies. Teachers also had opportunities to engage in the curriculum activities and labs and make cross-curricular connections to other units they had taught.

To support teachers with the implementation of the curriculum in the classroom, we provided curricular materials (available at www.climatechange.stanford.edu), multiple-choice and short essay pre- and posttests, a performance assessment, and, when requested, lab and demonstration equipment. Additionally, Stanford scientists visited classrooms, provided curricular resources, and interacted with the teachers to provide mentorship and support throughout the year. Given that climate science is an emerging discipline, the interactions and the professional relationships between the scientists and the teachers are particularly important and highly valued.

The Curriculum

The curriculum addresses some of the fundamental issues of climate science and the impacts of climate change on society and on global resources. We designed the curriculum based on principles of backward design (Wiggins and McTighe, 2005). As a team of educators, teachers and scientists, we decided what we wanted the students to know and be able to do, and how we would assess what they had learned. Then we designed the content and the activities of the curriculum to provide a scaffold to support that learning and provide optimal opportunities to talk and work together. The varied curricular activities invite students to engage with the scientific phenomenon of climate change as well as larger societal issues. Students have opportunities to work with authentic data, use the discourse of science by examining evidence and scientific claims, discuss the scientific consensus surrounding these claims, and investigate broader implications of various mitigation and adaptation strategies.

The curriculum unit leads students through a progression of understanding over the course of seven sections. Section 1 begins with students distinguishing between climate and weather, and considering the local impact of sea level rise due to climate change. This hook provides students the opportunity to think about their own connection to climate change. Students then learn about the Earth's energy budget (Section 2) and greenhouse gases (Section 3) to understand how excess carbon dioxide, with its ability to absorb and reradiate heat, is rapidly changing the climate. Section 3 ends with students looking at sources and sinks of carbon dioxide so that they realize that climate change is almost certainly caused mostly by humans. In Sections 4 and 5, students examine the effects of climate change to both physical and biological systems. Students examine ice core data as well as other physical datasets in Section 4 to consider the implications of climate change on the physical world. Similarly, in Section 5, students look at datasets of biological systems and think about the adaptations that humans need to make to adjust to the changing climate. Section 6 provides an opportunity for students to step back from the data and think about the process of science and how we use language. The final section on climate change mitigation requires students to examine and choose mitigation strategies to reduce carbon dioxide emissions as a team.

Each of the lessons contains different materials to support different classroom structures so that students participate in whole class discussions, and work in pairs and in small groups. As curriculum developers, we paid particular attention to the language demands of the learning tasks and of the assessments to ensure appropriate supports and scaffolds for students who are English learners. While the curriculum is comprehensive, teachers found ways to further adapt and modify the curriculum to fit the needs of their students.

Classroom Observations

To document the nature of student and teacher talk in the classroom, we recorded the proportion of students interacting in real time and videotaped the lessons for more in-depth qualitative analyses.

We constructed an instrument to document the level of student engagement and interaction. The instrument was piloted in science classrooms prior to the start of data collection. Research team members achieved interrater reliability on this student engagement instrument by obtaining 85% or greater agreement with a criterion scorer.

We visited participating classrooms at least three times during implementation of the 4–5 week unit to record information using the Student Engagement Instrument (Appendix A). Observers took mental snapshots of students as they worked, either individually, as a group, or as a whole class. Each student's behavior was recorded in one of three categories: engaged and interacting, engaged and not interacting, and disengaged. A student was considered "engaged/interacting" if he or she was seen in an on-task discussion with another student or the teacher. A student was categorized as "engaged/not interacting" if he or she appeared to be on-task but wasn't talking with others; typically behaviors such as listening, writing, and reading fell into this category. Finally, a student was considered "disengaged" if he or she was clearly doing other class work, distracting others, or talking off-task. For each observation, we indicated the class structure during that observation: individual work, group work, whole class, or some combination of the above. Four to six such observations were made during each of three visits.

In addition, we videotaped teachers and students in eight classrooms at least three times over the course of the unit. These classrooms were selected on largely practical and logistical grounds based on availability of observers and research assistants, the geographic proximity to Stanford, and the teachers' implementation schedules. Three researchers viewed each of the videos and met regularly to discuss their contents. Analytic themes were selected a priori while others developed through an iterative process of viewing, discussing, and coding the videos. Select segments were transcribed for additional analysis.

Pre- and Postassessments

To document student learning, we administered a pre- and postassessment (available at https://pangea.stanford.edu/programs/outreach/climatechange/sites/default/files/Student%20Pre%20post-test%202011-12%20v%203.pdf) to 742 students in 30 classrooms of 12 teachers. The assessment included a section that measured content knowledge (both factual and conceptual) using multiple-choice items and short open-ended essay questions. The items were constructed using backward planning. Climate scientists on the team began by identifying the main concepts students should understand and the skills they should have upon completing the unit. Then educators, educational researchers, and an assessment specialist went through an iterative process of identifying, evaluating, and revising performance tasks and test questions to measure students' pre and post knowledge and skills. Climate experts confirmed the accuracy of the content. The subsequent test questions were piloted in two middle- and high-school classrooms during a summer session to check for usability, internal consistency, and validity. Questions were revised based on the quantitative and qualitative analyses of student responses. They were revised again after year one of the study, and completion of the pre- and postassessments by 836 students in 19 classrooms.

The assessment also included select Likert scale opinion questions modified from the "Six Americas" study (Maibach et al., 2009). These items have been tested for validity and reliability and have been administered to thousands of people across the country by the Yale Project on Climate Change and the George Mason University Center for Climate Change Communication.

To participate in the study, teachers, students, and parents provided positive consent. The Stanford University Institutional Review Board evaluated and approved the study, the use of the above instruments, and the observation protocols.

FINDINGS

Below we report the results of our analyses of student learning and classroom discourse to answer our three research questions.

Question 1: What did students learn about climate change and to what extent have their opinions shifted after experiencing a climate change curriculum?

The primary goal of this project was to support and document student learning about global climate change. Thus, to better understand the level of student achievement in our target classrooms, we analyzed student achievement data as measured by our written assessment.

The assessment contained 15 multiple-choice questions, each worth one point. Of these 15 questions, students correctly answered significantly more questions on the posttest ($x = 11.86$, SD = 2.20) than on the pretest ($x = 10.22$, SD = 2.59) as measured by a paired-samples t-test ($t = 19.82$, $p < 0.001$). The greatest gains were seen on Question 5, related to the composition of earth's atmosphere (26.1% of students answered the question incorrectly on the pretest and correctly on the posttest) and Question 9 regarding climate change adaptation (24.9% of students answered the question incorrectly on the pretest and correctly on the posttest). The smallest gains were seen on questions in which a high percentage of students answered the question correctly on the pretest.

Of the 742 students who completed the assessment, 704 also completed six opinion questions. Student responses to these questions on the pre- and posttest are reported in Table I. Broadly speaking, students moved from a less aware, concerned, and certain view to a more aware, more worried, and more certain about climate change.

The percentage of students who are certain that global warming is happening increased from 41.7% on the pretest to 55.5% on the posttest. When asked about the scientific

TABLE I: Percentage of student responses to opinion questions ($n = 704$).

Question	% of Student Responses		National Average[1]
	Pretest	Posttest	
1. Assuming global warming is happening, do you think it is			
a. Caused mostly by human activities.	55.3	58.4	57
b. Caused by human activities and natural changes.	32.9	36.1	5
c. Caused mostly by natural changes in the environment.	5.0	2.0	33
d. None of the above because global warming isn't happening.	1.9	1.2	3
e. Other. Please specify.	1.4	1.3	1
f. Don't know.	3.5	1.0	n/a
2. Do you think global warming is happening? How sure are you that global warming (is happening/is not happening)?			
a. Very sure global warming is happening	41.7	55.6	n/a
b. Somewhat sure global warming is happening	42.7	34.8	
c. Don't know	11.4	6.6	
d. Somewhat sure global warming is not happening	3.0	2.6	
e. Very sure that global warming is not happening	1.3	0.4	
3. Which comes closer to your own view?			
a. Most scientists think global warming is happening.	49.9	59.9	47
b. There is a lot of disagreement among scientists about whether global warming is happening.	29.8	33.6	33
c. Most scientists think global warming is not happening.	2.1	0.7	3
d. Don't know enough to say.	17.9	5.8	18
4. How important is the issue of global warming to you personally?			
a. Extremely important	14.6	18.9	11
b. Very important	36.0	40.3	21
c. Somewhat important	34.3	33.9	39
d. Not too important	11.4	5.8	18
e. Not at all important	3.8	1.2	11
5. How worried are you about global warming?			
a. Very worried	22.3	24.7	17
b. Somewhat worried	49.9	58.4	46
c. Not very worried	21.5	14.4	24
d. Not at all worried	6.3	2.3	13

[1] Comparable/applicable national averages provided by the Six Americas study (Maibach et al., 2009).

consensus on climate change, nearly 50% of students indicated on the pretest that most scientists think global warming is happening and nearly 60% on the posttest. Students had the option of answering "don't know enough to say" or "don't know" to Questions 1, 2, and 3. In each case, fewer students indicated that they didn't know on the posttest than the pretest.

For Questions 1, 3, 4, and 5, we can also make comparisons to the responses of general public that were surveyed as part of the Six Americas Study (Maibach et al., 2009). For Questions 1 and 3, student responses on the pre- and posttests indicate that they grew increasingly more convinced than the general public that global warming is caused by human activity and more certain than the general public that there is general scientific consensus around the issue. For Questions 4 and 5, students' responses on the pre- and posttests indicate that the issue became increasingly more important to them and they are more concerned about climate change than those surveyed nationally.

In addition to these analyses, we replicated the year 1 study (Holthuis et al., 2012) of the relationship between student interaction and learning gains on the multiple-choice portion of the assessment (Table II). We found that the higher the average level of student engagement with interaction, the greater the average student learning gains ($r = 0.117$, $p < 0.05$). Also, the higher the level of

TABLE II: Pearson's correlation of student engagement and student achievement (Classroom level analysis, $N = 8$).

Involvement	Student Achievement (Overall Gain)
% Engaged and interacting	0.117[1]
% Engaged and not interacting	0.039
% Disengaged	−0.155[1]

[1] Correlation is significant at the 0.05 level (1-tailed).

disengagement in a classroom, the lower the gains ($r = -.155$, $p < 0.05$). The level of engagement, without interaction, is not significantly correlated with student achievement as measured by the posttest score.

Question 2: How did teachers and students talk about how we know about climate change?

The research team analyzed all the videotapes and identified recurring themes. We identified ways in which epistemic talk (how do we know) about climate was modeled, labeled and discussed by the teacher, and practiced by students.

Modeling

We observed teachers as they modeled a variety of questions to facilitate students' understanding of data. For example, near the beginning of the climate change unit, Teacher H1, a sixth grade teacher, projected a graph of CO_2 concentration over time (Fig. 2). She began the discussion by posing a question:

> *T[1]: "What does this graph show us?"*
>
> *S1: "It shows that the carbon dioxide concentration . . . over fifty years."*
>
> *S2: "It's a Keeling curve."*
>
> *T: "Why does the graph go up and down really fast?"*
>
> *S3: "The annual cycle."*
>
> *T: "So, what's the overall message?"*
>
> *S4: "Carbon dioxide emission is going up."*

Teacher H1 had students identify the core message communicated in the graph without using any specialized vocabulary or jargon. She elicited student thinking about the essence of the information, without using the terms "claims" or "evidence" explicitly. In doing so, she modeled the types of questions one should ask of a data set or graph.

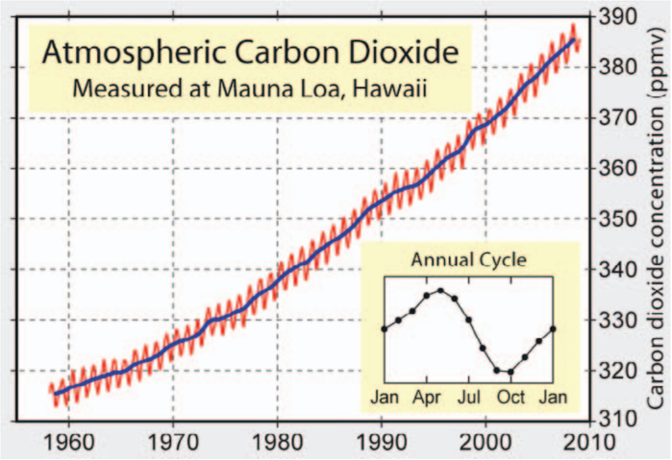

FIGURE 2: Graph discussed in Teacher H1's Class (Mauna Loa Atmospheric Carbon Dioxide, graph created by Robert A. Rohde from data published monthly by NOAA Earth System Research Laboratory (available at: http://www.esrl.noaa.gov/gmd/dv/data/index.php?parameter_name=Carbon%2BDioxide&site=MLO) and incorporated into the Global Warming Art project).

Labeling and Discussing

As we described in our conceptual framework, Bandura's social learning theory suggests that modeling is necessary but not sufficient. He argued that new behaviors—in this case, new ways of talking—should be labeled and discussed. For example, if a student uses evidence to make a specific and coherent claim about the effects of increased CO_2 in the atmosphere, that talk can be labeled as a scientific argument. The teacher and students can then dissect and identify the elements of a well-constructed argument. The videotapes captured teachers employing these strategies as they explicitly instructed students about how to construct an evidence-based claim. In the following transcript, Teacher L discussed the Global Land–Ocean Temperature Graph (Fig. 3).

> *T: "What is the evidence for the change in climate that we see here?"*
>
> *S: "CO_2 has increased."*
>
> *T:* (referring to the Y-axis) *"This is temperature."*

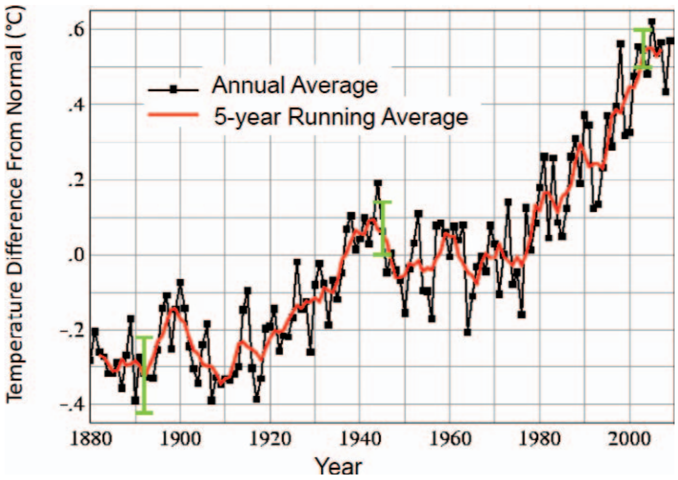

FIGURE 3: Graph discussed in the Teacher L's class (Global Ocean and Atmospheric Temperature, available at http://data.giss.nasa.gov/gistemp/graphs_v3/Fig.A2.gif).

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[1] *T = Teacher, S = Student*

S: "Oh, temperature."

T: "Average annual temperature has increased. How much?"

S: "Point 8."

T: "0.8°C. Over the period of when?"

S: (inaudible)

T: "1880 to 2000. So that is a good statement of evidence, right? So I've said what my graph shows, I've talked about what the trend is, I've said how much the trend has covered, and I've told you what years I was looking at. So, when [you] present evidence, that's the kind of statement that I'm looking for. I want a very concrete statement that has all of those pieces, if possible."

She modeled how to cite evidence and provided students feedback about the components that a model claim should include. In an earlier lesson she had emphasized similar expectations: "What was your evidence? Don't just tell me 'the graph,' be specific."

We also observed some clear differences in teachers' expectations for citing evidence. The passage below is transcribed from a conversation between Teacher H2 and a group as they studied a graph related to extreme weather conditions:

T: "What claim do you guys make?"

S1: "Over here the events are increasing."

T: "Are they increasing equally in all parts of the globe?"

S2: "Yes. Oh, not equally, but all increasing."

T: "So, what areas seem to be more affected? (Brief silence.) *So you guys aren't making a claim, you're making a generalization . . . so, a claim should be more specific. So looking at that, you need to have a more specific statement . . . if you weren't presented with this information, what statement could you make about this to base that?"*

S2: "More extreme . . ."

S1: "More populated areas."

S2: "More populated western areas."

Teacher H2's distinction between generalizations and claims implies that she expected a higher level of induction and greater specificity than the students originally provided. Similar feedback about the specificity of the claim was offered to another group.

Teacher D sent a very similar message to her students. A group of three students grappled to interpret a graph that shows an increase in the number of acres burned in the Western U.S. from 1960 to 2005.

T: "Tell me what the graph represents."

S: "This represents . . . dying."

T: "This says something about people dying?"

S: "No, this is floods, this is fire."

T: "What's the trend you see over time?"

S: (inaudible)

T: "So your claim is?"

S: "That most, a lot of disasters increase over years."

T: "Be very specific, 'so forest fires went up by___?' For your evidence tell me by how much. Give me the numbers involved."

In contrast, Teacher J communicated a different message about what constitutes a claim:

S: "Do you want us to include certain numbers, exact numbers?"

T: "It's up to you. . . . You don't have to state specific numbers. You can explain the trend."

It is unclear what students may have taken away from Teacher J's feedback. Is it acceptable for the claims to involve general patterns, or is the teacher referring to evidence? By "explaining the trend," is the teacher advocating for a claim about the underlying cause(s) of the data? Is Teacher J confusing language functions; does she actually mean "describe the trend," consistent with the tone of not expecting specific numbers? As we discuss in the implications section, these subtle but differing interpretations of argumentation raise questions about the outcomes of students' experiences with the curriculum more broadly.

Practicing Talk About Science and Climate Change

The curriculum provided opportunities for students to practice interpreting data and making claims that they could support. Many of the tasks were designed to include some form of data, such as a graph, visual, or table, and students were asked to provide evidence for claims. As a result, we captured many examples of students practicing this linguistic function.

We observed Teacher W as he made a point of going from group to group and asking students questions about the data and about their claims. In one such group, 6th grade students were discussing a diagram of the impact of climate change on asthma rates in the U.S. (Fig. 4). One student stated that industrialization has led to the increase in asthma rates. "Does he have some evidence for that?" the teacher asked the other students in the group. The students pointed to the figures and information provided in the resources and explained their reasoning: "Cuz if you follow this through, from here [points to 'industrial activities'], this goes up and then this goes up, all the way 'til you get to asthma." The teacher responds, "Interesting idea, I hope you put that one down there [on the paper]."

In this same class, other students in a small group were examining a graph (see Fig. 5) that showed the predicted magnitude of adverse impact on various natural ecosystems given an increase in temperature between 0°C and 4°C. One

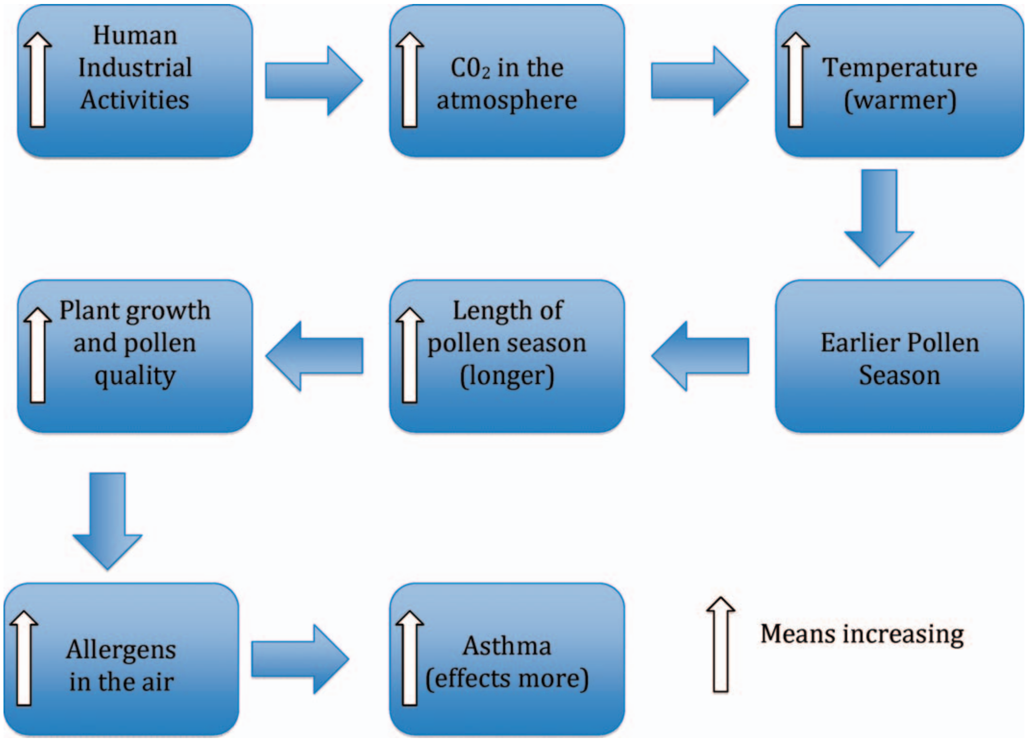

FIGURE 4: Graph discussed by students in Teacher W's class (Impact of Climate Change on Asthma).

student in the group made a claim that the magnitude of impact goes up over time (recently vs. later). Another student pointed out that "it doesn't really say timeline. It says 'Celsius'," They then revised their claim: "A temperature change of 4°C would badly change the environment."

Question 3: What classroom conditions support such talk?

By triangulating observational data and data from the videotapes of classroom talk, we identified three factors that help to promote or hinder *how do we know* talk: classroom

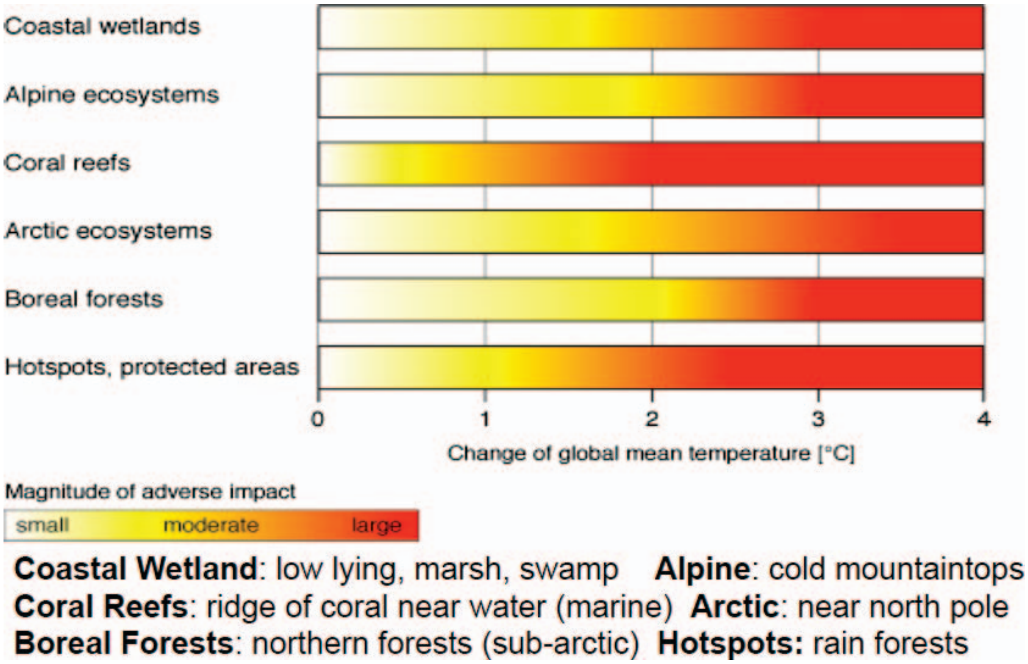

FIGURE 5: Graph discussed in Teacher W's class (Impact of Climate Change on Natural Ecosystems, available at http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/sondergutachten/sn2003/wbgu_sn2003_engl.pdf. Used with permission of the German Advisory Council on Global Change. Shading in the graph represents the magnitude of the adverse impact on various ecosystems from small (lightest) to large (darkest).

TABLE III: Descriptive statistics for student engagement data ($N = 198$ observations in 13 classrooms).

	Min	Max	Mean	SD
% of students engaged and interacting	0%	70.59%	28.26%[1]	6.35
% of students engaged and not interacting	0%	23.23%	65.58%[1]	7.94
% of students disengaged	0%	16.90%	6.16%[1]	6.78

[1] ANOVA indicates significant differences ($p < 0.01$) by class.

management, features of the curriculum, and a shift in the teacher's role as the intellectual authority in the classroom.

Overall Levels of Interaction and Disengagement

Using the observation instruments described above, we collected and analyzed implementation data for the sample as a whole, as well as by classroom.

On average, the majority of students were engaged but not interacting. Over a quarter were engaged and interacting, while a much smaller percentage of the students were disengaged (Table III).

An ANOVA test indicates statistically significant differences between classes ($p < 0.001$). For example, one teacher had a considerably higher than average rate of disengagement in her two classes ($x = 22.2\%$ and $x = 18.7\%$) than the rest of the sample ($t = 6.5$, $p < 0.001$). Videos from these same two classrooms are the only ones in which we did not hear the students or teacher talk about how we know what we know.

The Curriculum Matters

We observed and videotaped a variety of lessons and found that the teachers' questions closely related to features of the task. Teachers modeled, reinforced, and labeled *how do we know* talk and students practiced making a claim or justifying a conclusion when an activity required or included it. When the task at hand did not specifically ask for evidence or a data-supported claim or argument, the teacher and students did not engage in such discourse.

For example in Lesson 4, students worked in small groups to analyze the effect of global warming on physical systems. They examined various graphs (see Supplemental Figure 1 for an example, available in the online version of the journal or at http://dx.doi.org/10.5408/13-036s1) and in each case, they were asked to discuss the following:

1. Based on the graphs, what claim (conclusion) can you make about the impact of climate change?
2. What is your evidence for this claim?

These questions appeared to focus students' discussions. By including them explicitly in the student materials, analysis of the data wasn't left up to chance and students were required to make their reasoning explicit. During this lesson, we observed students in the classroom we visited as they asked each other the questions from the instruction sheet, interpreted the data provided, and discussed the possible claims that were or were not warranted by said data.

In contrast, in the final activity of the unit, students were asked to discuss and agree on mitigation strategies they would suggest reducing future carbon emissions. The task didn't require or suggest that students use the same type of argumentative talk as in the activities where the data were explicit. Rather, at this point in the unit, the assumption was that students had to apply what they had learned about the effects of climate change. As such, we observed students as they spent considerable amounts of time debating the pros and cons of various mitigation strategies without making specific references to data. They cited some of the conclusions made from previous lessons, but not the evidence itself.

Allowing Students to Make Sense of Data

In all of the classrooms that we observed, teachers spent some time during whole-class discussions and lectures in the typical pattern of discourse referred to as the Initiation-Response-Evaluation (IRE) pattern: the teacher initiated (I) a dialogue with a question, students responded (R), and the teacher followed up with a comment that evaluated (E) the student's response. Often the pattern was repeated in rapid fire. For example, Teacher G asked:

> *T: "What happens if I increase my input?"*
>
> *S: "Uh, it gets . . . it gets too warm."*
>
> *T: "It gets too warm. Ok."*
>
> *T: "What if I want to keep it at equilibrium and I increase my input."*
>
> *S: "Increase the output?"*
>
> *T: "Increase the output. Ok."*

We saw another example in this same class the following week:

> *T: "Ask a question about a graph on the board."*
>
> *S: "It looks like . . ."*
>
> *T:* (interrupts) *"What's written on your sheet? That's what I'm concerned about."*

There is a tension between the traditional IRE pattern of teacher–student interaction, sometimes referred to as authoritative (Mortimer and Scott, 2003), and authentic science talk. As Michaels et al. (2008) point out:

The kind of discourse that encourages scientific talk and argument is different—in subtle and not subtle ways—from the I-R-E pattern of discourse. To begin with, teachers ask questions that do not have "right" or "wrong" answers or to which they themselves don't know the answers. For example, a teacher might ask, "What outcome do you predict?" and follow up the initial question with comments such as, "Say more about that." (p. 90)

If a teacher does the intellectual work for students, she establishes herself as the intellectual authority. As long as she is the one with the answers, can this type of epistemological talk get truly established or inculcated? Does the teacher need to delegate her intellectual authority to establish the authority of evidence? And if so, how?

We saw some examples in which the teacher delegated some of her role as the intellectual authority. Teacher D made the most explicit reference to the authority of data. As she introduced a lesson about greenhouse gases, she asked students about the ability of greenhouse gases to trap heat.

> *T: "Who told you that they trap in heat?"*
>
> *S: "You."*
>
> *T: "Do you trust me?"*
>
> *S:* Many reply, talking over each other:
>
> *"Yeah."*
>
> *"You went to Stanford, you're pretty reliable."*
>
> *T: "Ok. Here's the thing. I'm probably a pretty reliable source. But today, we are going to do a lab to prove that greenhouse gases actually trap in heat."*

Here, Teacher D deferred authority to the data that students would be collecting. By raising the issue of trust, she implied that it was not she, but the evidence that provided the proof in science. Although the message could be more explicit and use of the term "proof" is discouraged by many science educators (Schwartz, 2007), she suggested a skeptical perspective on the source of information. Later in the lesson, students asked many tangential questions and Teacher D attempted to answer them. She vacillated between delegating intellectual authority and being the source of information. As a way to direct the intellectual task back to the student, teachers could ask students, "How could we find out?" or "What data would you need to answer that question?"

In another instance, Teacher S asked students to look at data showing the percentages of various gases in the atmosphere. She then asked the students to respond "True or False: Greenhouse gases are the most abundant gases in the atmosphere." A number of students answer "True," greenhouse gases are the most abundant. She asks Miguel to explain his answer.

> *T:* (to the class) *"Give Miguel your attention, he's going to explain."*
>
> *S: "I don't know . . ."* (inaudible)
>
> *T: "No, I don't know is not an explanation. You picked true, so we'd like an explanation."*
>
> *S:* (quiet as he looks at the data on the board)
>
> *T: "What do you know about greenhouse gases? How do you know they are the most abundant gases in the atmosphere?"*
>
> *S:* (inaudible) *"Because carbon dioxide, uhm, and other stuff."*
>
> *T: And other stuff. Ok, give him some love, for his effort. Does anyone disagree with Miguel's answer?"* (three students raise their hands)

Another student comes up and points out that CO_2 and methane are greenhouse gases and that the data indicate that they make up only a very small percentage of the atmosphere. In this manner, Teacher S makes the data the authority. She doesn't evaluate Miguel's answer, but indirectly evaluates his reasoning. She has become more of a facilitator, and less of the intellectual authority. By doing so, she allows the students to go through an important process of analyzing the data, making a conclusion, and discussing differences.

DISCUSSION AND IMPLICATIONS

We are inundated with information about our planet's climate and sometimes that information is contradictory. By providing students with a richer, comprehensive understanding of both what we know and how we know it, we prepare them to be better consumers of science and think more critically about climate change findings, predictions, models, and claims. This requires a shift in the instruction from an exclusive focus on content knowledge to one that aims to develop critical analytic skills and scientific habits of mind. For example, students come to not only understand the effects of human activity on climate change, but they also learn to identify and analyze the evidence for anthropogenic climate change and how that evidence has built over time. Ultimately, we hope students can then evaluate claims made outside of the science classroom and decide if they are justified given the data.

Our research replicated previous findings that the more students interact with the teacher and each other, the more they learn, while simply appearing engaged, quiet, and seemingly on-task has no relationship to learning. We were able to identify how students and teachers talk about the epistemological basis of climate science. We documented ways in which teachers modeled and labeled such talk and provided opportunities for students to practice using this discourse themselves. Not surprisingly, we found that this type of talk was high when the task at hand explicitly asked for it and much lower, or nonexistent, when classroom management was lacking. We also saw that teachers had differing expectations for what makes a good claim. Some teachers emphasized specificity while others were looking for generalizability. Finally, we observed that such talk requires a shift in the role of the teacher—from ultimate intellectual authority to facilitator.

But this poses some challenges for teachers who teach climate science. As Hodson (2009) states: "Productive talk doesn't just happen; it has to be carefully planned and sustained by judicious teacher interventions. Ultimately, the success of talk-based classroom activities depends on establishing a classroom environment in which student–student interaction is encouraged and supported" (p. 286). As we found, the same is true for climate change education and it suggests implications for both curriculum and professional development.

Climate Change Curriculum

Teachers and students need fertile curricular soil to talk about how we know. For too many years, science curricula and textbooks have been criticized for presenting students with hundreds and hundreds of pages of what we know about the natural world but much, much less about how we know it (Penney et al., 2003). Science is presented as a body of knowledge, with only a few scientists and the nature of their work highlighted. The research findings behind the content are rarely provided.

To remedy this imbalance, we designed curricular materials—text, slides, activities, demonstrations, labs, assignments, and assessments—to provide a more comprehensive understanding of both what we know about climate change and the evidence and data supporting those conclusions and predictions. But what are some characteristics of materials that allow students opportunities to explore the data and provide them opportunities to interact and practice using science talk?

We recommend that curricular materials be designed around not just content objectives but competency, or skills, objectives as well. The middle school and high school curricular materials developed by the Stanford Climate Change Education Project has among its six objectives that "Students will be able to identify various sources of evidence used to chart climate and apply the evidence to determine the proximate and ultimate causes" and "Students will use data and evidence to justify claims relating to climate, climate change, and mitigation." From these objectives, we designed demonstrations, lab activities, lectures, and assessments. We further advise that group activities and labs be suitably rich, open-ended, and productively uncertain so that success depends on all students being engaged and interacting (Lotan, 2003).

Professional Learning for Teachers

An important implication of this work relates to professional learning opportunities for teachers. Scientific argumentation and our epistemological understanding of climate science are unfamiliar to most science teachers. They need a new set of skills. The teachers in this study expressed interest, willingness, and enthusiasm to gain these skills to successfully implement the pedagogy in the classroom. Thus, our workshops included conversations about the theoretical underpinnings of argumentation and practical ways to discuss with students how we know about climate change. We modeled the pedagogy, and provided teachers with opportunities to discuss how their students might respond. The teachers spent time engaging with the evidence to gain experience interpreting data, and making and justifying claims.

We saw, however, that some teachers in our sample were unable or hesitant to ask students to engage in argumentation when there were serious classroom management issues (as measured by very high rates of disengagement). While the level of disengagement might be both a cause and effect of mismanagement, we are assuming the former. As such, there are at least two possible explanations for this finding. In classrooms with high disengagement, teachers might be spending most of their time trying to maintain order, correcting behaviors, and facilitating student work. They might not attempt discussions about how we know about climate change for fear that even a greater number of students will get off-task. Second, as Sampson and Blanchard (2012) point out, many teachers they worked with voiced concerns about their students' ability to engage in argumentation. Professional development needs to help develop teachers' pedagogical content knowledge and also provide teachers with management tools and explicit modeling/debriefing on classroom management strategies and group work techniques. Such professional learning opportunities are critical not only to climate change education, but to science more generally as teachers begin to implement the Next Generation Science Standards. The scientific practices of analyzing and interpreting data are a critical component of these new standards. As we learned, the pedagogical skills necessary to translate these ideals to the classroom require a tremendous amount of time and effort as well as ongoing support.

We also noted that teachers provide varying interpretations of what makes a legitimate claim: specificity or generalizability. Teacher L and Teacher H2 both instructed their students that a claim should be very specific, while Teacher J instructed her students that a claim doesn't have to "state specific numbers" but should summarize a general trend. We argue here that neither interpretation is more correct than the other. Rather, the type of claim expected should follow from the core questions identified by the curriculum or subject area. For example, a chemist may construct claims that lean more toward providing explanations at the molecular level. Similarly, students' claims—whether general or specific—should help advance their understanding of climate change in line with the goals of the curriculum. Thus, professional development can provide teachers with opportunities to discuss and identify the characteristics of a good claim in light of their curricular goals.

The Goals of Climate Change Education

This leads us directly to a final implication: broad goals—whether related to content knowledge, competencies, attitudes, or actions—should be clearly identified. Argumentation is a means toward an end, not necessarily the end itself. Ultimately, climate change education has real consequences. We are in a crisis caused by human behavior that can also be mitigated by human behavior. While students may understand the facts of climate change, they may still continue to refute its existence or its causes. Or they may accept the anthropogenic cause of climate change but be unable or unwilling to change their own behaviors to reduce carbon dioxide emissions or adopt strategies to adapt to the predicted climate changes.

This suggests further investigation to answer some difficult questions regarding students' concerns and interests. For example, students showed significant positive shift from pre- to posttest in their responses to the opinion questions. Further classroom research might tell us if the quantity and qualities of *how do we know* talk in a classroom or other variables affect students' interest, concern, or certainty, about global climate change. Similarly, we provided materials that broadened participants' view of global climate change and introduced specific strategies that they can do as individuals. However, we don't yet have a clear understanding from the data whether other types of goals were met. For example, did teachers and students gain a sense of empowerment? Did students increase their capacity and willingness to make age-appropriate behavioral changes?

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APPENDIX A: Science Student Engagement Instrument.

Teacher: ___________________ Period: __________ *Obs Day #_________ Date: ______________ Lesson/Activity: ______________________ Scorer: ______________

	Engaged/ Interacting (verbally)	Engaged (but not interacting)	Off -Task/ Disengaged	Total	
Time 1 ______________					Whole Class Groupwork Individual
Time 2 ______________					Whole Class Groupwork Individual
Time 3 ______________					Whole Class Groupwork Individual
Time 4 ______________					Whole Class Groupwork Individual
Time 5 ______________					Whole Class Groupwork Individual
Time 6 ______________					Whole Class Groupwork Individual
TOTALS					

* First, second or third day of observations.