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Climate Change Professional Development: Design, Implementation, and Initial Outcomes on Teacher Learning, Practice, and Student Beliefs

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Abstract In this work, we present the design, implementation, and initial outcomes of the Climate Academy, a hybrid professional development program delivered through a combination of face-to-face and online interactions, intended to prepare formal and informal science teachers (grades 5–16) in teaching about climate change. The Climate Academy was designed around core elements of successful environmental professional development programs and aligned with practices advocated in benchmarked science standards. Data were collected from multiple sources including observations of professional development events, participants' reflections on their learning, and collection of instructional units designed during the Academy. Data were also collected from a focal case study teacher in a middle school setting. Case study data included classroom observations, teacher interviews, and student beliefs toward climate change. Results indicated that the Climate Academy fostered increased learning among participants of both climate science content and pedagogical strategies for teaching about climate change. Additionally, results indicated that participants applied their new learning in the design of climate change instructional units. Finally, results from the case study indicated positive impacts on student beliefs and greater awareness about climate change. Results have implications for the design of professional development programs on climate change, a topic included for the first time in national standards.

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Introduction

Climate change is recognized as one of the most pressing global challenges facing society (Jickling, 2001; NRC, 2012; Roehrig, Campbell, Dalbotten, & Varma, 2012). As a result, for the first time climate change is included in benchmarked standards for K-12 science education in the USA (NGSS Lead States, 2013). Yet, evidence indicates that learning about climate change is conceptually challenging for students and that teachers are ill-prepared to share the science and implications of climate change research with their students (Johnson et al., 2008; Shepardson, Niyogi, Roychoudhury, & Hirsch, 2012). Specifically, many teachers have limited formal preparation with climate change, as it was not a topic typically included in science education during their own disciplinary study (Hestness, McGinnis, Riedinger, & Marbach-Ad, 2011).

While professional development (PD) can play a key role in improving teachers' understanding and preparedness to address issues around climate change, little is published to date on PD approaches specific to climate change education that address the Next Generation Science Standards (NGSS) (e.g., Ellins et al., 2014). In this work, we present the design, implementation, and initial outcomes of the Climate Academy—a hybrid PD program delivered through a combination of face-to-face and online interactions, intended to help formal and informal science teachers (grades 5–16) teach about climate change. More specifically, we investigate the following question: *How can we support the design of PD programs grounded in the NGSS that promote changes in teacher learning, instructional practice, and student beliefs around climate change?*

We first present relevant literature that connects climate change education and teacher PD. Subsequently, we present our approach to the design and implementation of the Climate Academy and discuss findings regarding the impact of the Academy on teachers' learning. We end with the presentation of a focal case study in a middle school context, including discussion on instructional practice and outcomes on student beliefs toward climate change. Based on our findings, we conclude with suggestions that can support the development of PD programs that promote teacher engagement and learning with climate change.

Literature Review

Students' Conceptions of Climate Change

Although scientists have been studying climate change since before the industrial revolution (IPCC, 2013), it has only recently been included in US K-12 science standards. Specifically, the NGSS address climate change explicitly within key earth science concepts such as energy and human impact on the planet. The presence of climate change in US standards has the potential to influence classroom instruction over the coming years (Wise, 2010). Yet, climate change continues to be recognized as a sensitive science topic that teachers are frequently reluctant to teach (Hodson, 2013; McGinnis & Simmons, 1999; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006). By sensitive, we mean topics that are debated within the scientific community which rely on evidence constrained by uncertainty. For example, several future scenarios are predicated when considering increase in global temperature by the year 2100 depending on which variables and algorithms are utilized in the calculations (IPCC, 2013). Helping students make sense of such controversies will require significant support for teachers as they too come to understand climate science (Holthuis, Lotan, Saltzman, Mastrandrea, & Wild, 2014).

Several studies demonstrate that students often hold incomplete or alternative conceptions related to climate change. For example, a large body of work published by Boyes and Stanisstreet (1993, 1994, 1997, 2001) demonstrates that students tend to consider the ozone layer and its depletion as directly linked to climate change. This is problematic as the ozone layer has little impact on the rate or intensity of climate change over time (IPCC, 2013). Research also indicates that students confuse climate and weather, lack an understanding of the greenhouse effect on climate, and have difficulty comprehending the impact of climate change on the earth's spheres including oceans, weather, animals, plants, and land (Pruneau, Gravel, Courque, & Langis, 2003; Shepardson, Niyogi, Choi, & Charusombat, 2009).

Other studies found that students tend to reason that generally pro-environmental activities such as reducing pollution, protecting rare species, and cleaning streets can mitigate climate change (Boyes & Stanisstreet, 1993, 2001; Pruneau, Moncton, Liboiron, & Vrain, 2001). These actions are beneficial to the environment in general, but do not directly influence changes in climate (IPCC, 2013). Particularly problematic, however, is the idea that climate change will not happen in one's lifetime and that climate change claims are exaggerated such as the non-normative belief that a couple degrees of change in global temperature will not amount to adverse effects (Andersson & Wallin, 2000; Gowda, Fox, & Magelky, 1997). These pervasive notions are demonstrated by students and adults alike and need to be addressed as teachers provide climate change education in their classrooms.

One way to address incomplete science notions is by focusing on the analysis and interpretation of scientific data (Kirk, 2011). Analysis of geoscience data such as fluctuations in precipitation and temperature is a key concept within NGSS and can help students detect associated impacts (e.g., sea level rise). Organizations such as the Center for Operational Oceanographic Products and Services have already gathered oceanographic data along the US coasts for over 200 years allowing students to look for areas where sea levels are rising in the US and make inferences as to what is causing sea level rise. Similarly, Climate Wizard (2009) allows students to examine past and predicted changes in temperature and precipitation throughout the world while manipulating a range of variables. These resources can be helpful to teachers as they consider the dynamic evidence supporting a changing climate.

While examining the evidence supporting climate change is crucial, teachers must also address actions that students and communities can take to have a positive impact on climate change and avoid gloom-and-doom perspectives (Johnson et al., 2008). PD programs represent a promising pathway for helping teachers gain access to resources that support student learning and engagement with climate science in their communities. Thus, it is imperative that teachers seek out PD that will provide sufficient content knowledge and resources to address their own understanding of climate change and subsequently their students' learning.

Characteristics of Effective Climate Change PD

Although research on climate change PD is limited, the literature indicates that successful environmental education PD programs are designed around three core elements: (a) science content (i.e., what teachers need to learn); (b) good scientific and pedagogical practices (i.e., what teachers need in order to teach the content); and (c) use of the outdoors to understand the local environment most familiar to them (King, Shearon, Burgette, & Sivin-Kachala, 2012; Shepardson & Niyogi, 2012; Sondergeld, Milner, & Rop, 2014).

Teacher content knowledge is a critical component of teacher quality (Schmidt, 2001). Teachers who lack strong content knowledge are more likely to rely on science textbooks, ignore student concepts, and misrepresent the science, thus reinforcing student alternative conceptions (Gess-Newsome, 1999). While most teachers feel comfortable teaching about earth systems, they have difficulty addressing climate topics such as the greenhouse effect, consequences of climate change for specific regions, or scientific evidence surrounding climate change (NRC, 2012). The lack of knowledge surrounding key aspects of climate change is problematic because it makes teachers vulnerable to sources of information that attempt to disprove that climate change is happening (NRC, 2012). Most importantly, lack of knowledge is problematic because science teachers are the main source of information about climate for students (Dupigny-Girouz, 2010). As a result, climate PD programs should explicitly address teachers' knowledge of earth's systems and climate science.

Similar to content, teachers need strong scientific and pedagogical strategies for teaching climate science topics to students. This idea is consistent with Shulman's (1987) pedagogical content knowledge, a body of knowledge lying at the intersection of content and pedagogy that makes content comprehensible to students. According to Shulman, it is the subject matter knowledge and the associated pedagogical content knowledge that challenge teachers who must learn about a new topic and then understand how to convert their new knowledge into a pedagogical form. Specific to teaching about climate change, teachers must acquire pedagogy for science inquiry driven by practices advocated in NGSS (Kubitskey, 2006; NGSS Lead States, 2013). Such practices highlight the need to analyze and interpret data, develop and use models, highlight connections between science and technology, and intertwine teaching and formative assessment to move students toward increasingly more sophisticated conceptual understanding (Herman, 2013). Thus, effective climate PD must help teachers improve their pedagogical understanding of how to convey climate science content to their students.

Finally, when teaching about climate the initial focus should be relevant to teachers and their students' local environments where they can understand issues most familiar to them. If teachers and their students do not understand the environment where they live, they will be less likely to understand environments that are distant and foreign to them, and thus less inclined to engage with mitigation strategies (Sondergeld et al., 2014). As a result, climate change PD should establish connections to teachers' local context.

Climate Professional Development and Teacher Learning

Research indicates that effective PD can have significant benefits for teachers because it helps improve their capacity to understand scientific evidence around climate change and represent what climate science shows (Johnson, 2011; Lynds, 2009). To date, however, little empirical work has been conducted regarding the design, implementation and outcomes of climate change PD programs. Ellins et al. (2014), for example, designed a two-part teacher PD program as part of the *EarthLabs Climate* project, a comprehensive climate effort focusing on curriculum development, teacher learning, and evaluation. The PD enabled a small group of exemplary teachers who have reviewed and tested the *EarthLabs Climate* modules to lead a summer workshop introducing high school teachers to the modules. Results indicated that participants appreciated the PD activities (e.g., science presentations, hands-on activities, working with data, discussion of teaching methods, and discussion about content implementation), improved their climate knowledge, and increased their confidence in teaching the three main topics addressed in the PD: (a) climate and the cryosphere; (b) climate, weather, and the biosphere; and (c) climate and the carbon cycle.

Moving beyond teacher learning to examine student outcomes, Holthuis et al. (2014) presented a teacher PD program focusing on the science of global climate change, curricular materials, and pedagogical strategies. The curriculum unit utilized in this work led students through seven sections focusing on understanding climate and weather, learning about the earth's energy budget and greenhouse gases, examining the effects of climate change to physical and biological systems, thinking about the role of language in science, and introducing mitigation strategies to reduce carbon dioxide. Subsequently, Holthuis et al. (2014) conducted in-depth studies of participating teachers' classrooms examining student outcomes. Their findings indicated significant gains from pre- to post-assessment in students' content knowledge and a shift in their opinions about climate change.

While these studies provide important insights, they focus on PD efforts centered on specific curricula (e.g., *EarthLabs*). Yet, survey data indicate that teachers spend little time on units focusing explicitly on climate change but rather integrate climate topics with other materials (Hirabyashi, 2011). As a result, it is also important to provide PD efforts that help teachers design their own instructional units using credible climate science content, pedagogical practices advocated by NGSS, and local perspectives (Johnson et al., 2008). In this work, we present a PD program that seeks to strengthen teachers' knowledge and understanding of the scientific principles for climate change in order to support the design and implementation of climate change topics in their own school curricula. We present initial learning outcomes from a cohort of teachers and further instantiate our efforts by sharing a focal case study in a middle school classroom, where we discuss teacher learning, instructional practice, and student outcomes.

Methods

Context of the Study: Description of the Climate Academy

This work is situated in the context of MADE CLEAR (Maryland and Delaware Climate Educational Assessment and Research Project), a regional project focused on the implementation of a comprehensive climate change education plan across Maryland and Delaware. A key component of MADE CLEAR is a yearlong Climate Academy that brings together educators in grades 5–16 through face-to-face events and online interactions.

The design of the Climate Academy was based on a collaborative effort among climate scientists, learning scientists, practitioners, and policy stakeholders. The cross-disciplinary expertise of the design team was intended to enhance participants' understanding of climate science and support the development and implementation of climate change topics in participating teachers' curricula. The work reported in this study characterizes our findings on the first Climate Academy of the project. Follow-up Academies are ongoing. The Climate Academy reported here included three primary components: (a) an intensive residential weeklong summer institute (46 h); (b) four virtual follow-up sessions on challenging climate science concepts; and (c) two face-to-face follow-up sessions for reflection and development of instructional units on climate change. Each virtual session was 2.5 h (10 h total) and was conducted using web-conferencing software. Each face-to-face session was 4 h (8 h total) and took place in a convenient geographic location. Thus, the Academy provided a total of 64 h of PD.

The Climate Academy was designed around three core elements supported by the literature: science content, pedagogical practices supported by NGSS, and outdoor activities in the local environment. The Climate Academy explicitly addressed content that has been found challenging for students both during the summer institute and academic year refresher experiences where teachers learned about the difference between weather and climate, the carbon cycle and its relation to the greenhouse effect and global warming, the role of humans in climate change, climate change impacts, and solutions to climate change (how people can adapt and mitigate a changing climate).

To gain a better understanding of content, teachers engaged in standards-based pedagogical activities by doing science with peers who held diverse prior experiences (Barnett et al., 2014). A number of activities were conducted in the outdoor setting of the Climate Academy, which was surrounded by coastal wetlands ideal for conducting inquiry-based work on climate and demonstrating the effects of climate on one's local context and earth's spheres (see Fig. 1). Finally, to establish connections between new learning and practice, all teachers designed instructional units (3–5 h of instructional time) that integrated climate science in their curricula, reflected on their designs and shared ideas with peers. These activities engaged

Fig. 1 Outdoor space and activities of Climate Academy (measuring sea level)

teachers in thinking about their teaching and how to implement the content with their students. Table 1 provides an overview of the Climate Academy in relation to core elements of effective environmental PD and expected outcomes.

Participants

Participants ($N = 27$) in the Academy included middle school ($N = 14$), high school ($N = 7$), higher education ($N = 2$), and informal science teachers ($N = 4$) from Delaware ($N = 16$) and Maryland ($N = 11$). Teachers were recruited through mailing lists managed by the Delaware and Maryland state departments of

Table 1 Description of Climate Academy in relation to key elements of effective PD

PD core element	PD event	Expected outcomes
Climate science content	Summer Institute	Build teacher content knowledge of climate change supported by evidence
Human impacts	Virtual session 1	
Weather versus climate		
Carbon cycle		
Effects on Earth's systems		
Solutions		
Climate science pedagogy	Summer Institute	Strengthen skills in designing pedagogical activities for teaching and assessing climate change aligned with NGSS expectations
Analyze and interpret data	Virtual sessions 2–4	
Develop and use models: carbon cycle; combustion; sea level rise	Face-to-face session 1	
Integrate technological resources	Face-to-face session 2	
Integrate teaching and formative assessment		
Relevant content	Summer Institute	Make content relevant to local impacts
	Face-to-face session 1	
	Face-to-face session 2	

education, correspondence with district curriculum/science coordinators, and direct email announcement to school principals. Specifically, middle school, high school, and informal educators interacting with middle and high school students were recruited for participation since NGSS identify climate change science within its disciplinary core ideas for students at these grade levels. NGSS do not identify climate change-specific standards for elementary grades; thus, elementary teachers were not recruited. All middle school teachers taught general science for grades 5–8, while high school teachers taught physics, biology, chemistry, or earth science for grades 9–12 including Advanced Placement (AP) courses. Informal education teachers designed and implemented environmental education programs at their respective state parks, and all higher education participants were faculty members in science education. Participants attended the Climate Academy voluntarily and received financial incentives for participation.

Teacher Data

Data for all teachers were collected from two sources: daily reflections on PD activities from the residential summer institute, and instructional units on climate change topics developed by all participants throughout their participation in the Climate Academy. All reflections were structured around the same three prompts to facilitate consistent responses: (a) What did you learn from this session? (b) What do you still have questions about? and (c) What additional supports could you use? Although data were collected from all participants at each individual PD event, for the purposes of this study we only utilized data for participants who attended the entire weeklong summer institute and at least two follow-up sessions ($N = 17$). This allowed us to document the ways in which participation in sustained PD efforts (51–54 h over the course of 1 year) can support changes in teacher learning and instructional practice. It also allowed us to understand the ways in which participants continued to develop their instructional units when they returned back in their classrooms. Further, since our interests are focused on the ways in which teachers (formal and informal) can support K-12 students' learning of climate change, higher education participants were not included in our analysis.

Focal Case Study Data

To gain a closer understanding of teacher and student outcomes as a result of participation in the first Climate Academy, we collected and analyzed data from a focal case study participant. Additional case studies at different grade levels are ongoing. The case study participant, Mr. Finley, was an experienced middle school teacher, who taught seventh- and eighth-grade science to approximately 150 students each academic year. He worked in a suburban school located within the mid-Atlantic region of the USA. At the time of the study, the school enrolled 679 students: 71 % White, 14 % African American, 9 % Asian, 6 % Hispanic, and <1 % Hawaiian. Mr. Finley was selected for in-depth case study analysis for three reasons. First, as often typical of middle school science teachers, he exhibited little prior knowledge of climate science at the beginning of the Academy but demonstrated increased engagement with the materials and attended all PD activities (68 h). Second, he taught in a school located in a suburban area experiencing tremendous population growth and facing climate change impacts representative of the mid-Atlantic region (e.g., sea level rise). Finally, Mr. Finley's school was located in proximity to our research team, which allowed for in-depth data collection.

Data from Mr. Finley's classroom were collected from three different sources including classroom observations, interviews, and surveys on students' beliefs around climate change. First, we conducted classroom observations ($N = 12$) over a 3-week period documenting the implementation of Mr. Finley's instructional unit designed during the summer institute in seventh- and eighth-grade science classrooms. Second, we conducted a semi-structured interview with Mr. Finley both before and after the implementation of his instructional unit. Interview questions focused on the following topics: (a) goals and objectives of Mr. Finley's instructional plan (e.g., Can you briefly describe the instructional unit you designed during the Climate Academy? What are the specific goals and objectives of this unit?); (b) resources needed to implement the unit (e.g., What curricular and technology resources did you include in your unit? How did you identify those resources?); (c) assessment strategies (e.g., What kinds of assessments will you use to measure student learning?); (d) expectations for student learning outcomes (e.g., What are the learning outcomes you expect your students to achieve by the end of the unit?); and (e) challenges expected and encountered during the implementation of the unit (e.g., What challenges do you expect, if any, as you enact your unit?).

Finally, we collected data on students' beliefs toward climate change, both before and after the implementation of Mr. Finley's instructional unit, using the 15-item *Six Americas* survey (Yale/George Mason, 2009). The survey is divided in four areas: (a) beliefs (e.g., Do you think global warming is happening?); (b) involvement (e.g., How worried are you about climate change); (c) behavior (e.g., How often have you punished companies that are opposing steps to reduce global warming by not buying their products?); and (d) preferred societal response (e.g., Do you think global warming should be a low, medium, high, or very high priority for the next president and Congress?). The survey has been tested for validity and reliability through administration to thousands of people across the country, including middle and high school students (Holthuis et al., 2014; Maibach, Roser-Renouf, & Leiserowitz, 2009). A total of 127 students (85 % response rate) completed the pre-administration of the survey, while a total of 146 students (97 % response rate) completed the post-administration of the survey. Although we administered the survey in its entirety, for the purpose of this work we were only interested in examining students' beliefs and personal involvement toward climate change since Mr. Finley's instructional unit did not address behavior and societal response issues (Fig. 2).

Teacher Data Analysis

Participants' daily reflections from the summer institute ($N = 62$) were analyzed qualitatively using the constant comparative method (Bogdan & Biklen, 2003).

Only data from the 17 participants who met requirements for participation in the study were included in the analysis. Specifically, all three authors repeatedly read reflections in order to identify similarities and differences among participant responses as well as emergent themes specific to climate science content and pedagogy presented in the Climate Academy (Miles & Huberman, 1994). Frequency counts were calculated to indicate the number of teachers who referenced a particular theme, and relevant excerpts were selected to illustrate each theme.

Instructional units developed by participants ($N = 16$[1]) were analyzed using an a priori coding scheme directly corresponding to the three core elements of the Climate Academy: (a) *Climate change content*: human impacts and climate, weather versus climate, carbon cycle, sea level rise, and mitigation and adaptation strategies; (b) *Climate change pedagogy*: analyzing data, developing and using models, integrating technological resources, and utilizing formative assessment; and (c) *Local impacts*: utilizing climate change content relevant to local impacts. Frequency counts were calculated to identify specific content and pedagogical strategies reflected in each instructional unit. All three authors coded 100 % of the data. All discrepancies were discussed and addressed until 100 % agreement in coding was reached.

Focal Case Study Analysis

Case study data were analyzed using different approaches. Observation and interview data were first transcribed and saved on a shared password-protected server to facilitate ongoing analysis. They were subsequently analyzed qualitatively to provide a rich description surrounding the implementation of the instructional unit focusing on climate science content and pedagogical strategies. Classroom artifacts such as photographs and student work were used to triangulate our findings (Bogdan & Biklen, 2003). Finally, we conducted a member check by sharing our case study description with Mr. Finley to verify that our analysis accurately captured his experience and changes were made where necessary.

Student survey data were analyzed using established guidelines provided by Maibach and colleagues (Maibach, Leiserowitz, Roser-Renouf, Mertz, & Akerloft, 2011; Maibach, Leiserowitz, Roser-Renouf, & Mertz, 2011). Specifically, the *Six Americas* survey has been utilized to describe student views on climate change resulting in six profiles. The six profiles are as follows: Alarmed, Concerned, Cautious, Disengaged, Doubtful, and Dismissive. At one end of the spectrum, the *Alarmed* are very concerned about the issue of global warming and support aggressive action to reduce it. At the other end, the *Dismissive* do not believe global warming is real and likely to believe it is a hoax. Between the two spectrums are the four groups of *Concerned*, *Cautious*, *Disengaged,* and *Doubtful* with lower certainty and issue engagement.

For the current data analysis, student pre- and post-responses were exported into excel and the Statistical Package for the Social Sciences (SPSS). Student profiles

[1] Two teachers worked together and thus we collected 16 units from the 17 participants.

were calculated for both the pre- and post-administration of the survey. Additional analysis was conducted to determine the audience segmentation of students before and after Mr. Finley's instructional unit. These analyses follow the SPSS script for the discriminant analysis as provided by the original authors of the *Six Americas* survey and found in Maibach, Leiserowitz, Roser-Renouf, and Mertz (2011). Each profile was assigned a numerical value that ranged from 1 (*Alarmed*) to 3 (*Cautious*) to 6 (*Dismissive*). These values were used to facilitate the statistical analysis of this ordinal data.

Results

In this section, we present the findings of our work organized in four areas: (a) teacher learning of climate science content, (b) teacher learning of pedagogical strategies for teaching climate change, (c) analysis of instructional units, and (d) focal case study.

Teacher Learning of Climate Science Content

Analysis of PD reflections indicated that teachers found the content of the Climate Academy valuable to their learning. As shown in Table 2, most teachers indicated learning new content related to the causes of climate change, the relation between carbon cycling and climate change, and impacts of climate change related to sea level rise.

The residential summer institute of the Climate Academy began by providing a general overview of the causes of climate change, focusing more explicitly on the mechanisms by which changes in climate occur. Understanding the mechanisms that support climate change is fundamental for conveying climate change education to students, yet results indicated that many teachers had not previously encountered this content in their own formal and informal education. Almost all teachers (88 %), for instance, provided examples of how participation in the summer institute improved or deepened their understanding related to the difference between climate change and global warming, the difference between weather and climate, the causes of climate change, the causes around the rapid increases in greenhouses gases, the primary greenhouse gases in the earth's atmosphere, and the ways in which scientists have measured climate change over time. Specific excerpts and remaining questions expressed by participants are shown in Table 2.

Carbon cycling was also an important component of the Climate Academy because it is typically included in national science curriculum and offers a salient segue for educators to discuss climate change with learners. Findings indicated that most educators (70 %) solidified their understanding on the connection between carbon cycling and climate change as well as the connection between ethanol burning and climate change (see Table 2). For example, Katie, an informal science educator, indicated that she learned new content around the molecular structure of ethanol and the way combustion breaks ethanol into CO_2 and H_2O, releasing energy in the form of heat and light. In this example, Katie is referring to an activity

Table 2 Teacher learning of climate science content

Content	No. of teachers	Key sample excerpts from reflections	Remaining questions/required support
Climate change: definition, causes, and evidence	15 (88 %)	I understood the difference between climate change and global warming as well as climate and weather	What exactly is going on at the molecular level for the greenhouse effect to occur?
		I gained a better understanding of how greenhouse gasses cause an increase in temperature by turning infrared energy into heat energy through the moving of their bonds	What are the projected implications (e.g., projected changes in precipitation) for our region?
		I understood how scientists have measured climate change over time	I want to learn more about the effects of acid rain on the environment; I was wondering about the troposphere extending as a consequence of climate change
Carbon cycling	12 (70 %)	I learned that matter cycling is closely connected to climate change	How to make the intellectual leap from energy usage to pounds of carbon
		I learned about the carbon cycle and how the molecular breakdown of ethanol works	What are alternative ways of generating energy and what is the carbon cost associated with each?
			What are communities doing to lower their carbon footprint?
Sea level rise	10 (59 %)	I learned why sea level rise is occurring—specifically for my locality and the polar ice connection	More information about seesaw effect with rebound action from glacier melt

presented during the summer institute where ethanol combustion produced carbon dioxide gas and water vapor. In a classroom setting, this activity helps students visualize ethanol using gum drops as atoms and tooth picks as bonds between atoms. Students are typically asked to rearrange the model after combustion to demonstrate how two new molecules are created from ethanol, thus demonstrating the law of conservation of matter—the cornerstone of the carbon cycle. The increase in carbon dioxide is produced mainly by humans through combustion of fossil fuels and plays a critical role in climate change. As a result, the activity introduced during the Academy offered teachers an opportunity to transition into deeper conversations about the mechanisms of climate change.

Finally, a number of participants (59 %) indicated new learning around the causes of sea level rise and the connection between climate change and sea level rise (see Table 2). Megan, an eighth-grade science teacher, stated: “I learned why sea level rise is occurring—specifically for my locality and the polar ice connection.” Megan made an important connection in this reflection—there is a link between what occurs on a regional and global scale. Ice that melts at the poles can directly influence sea level rise around the Delmarva peninsula. For many students, this connection between micro- and macro-phenomena is difficult to conceptualize. Nevertheless, many participants remained interested in learning more about climate change in terms of regional and local impacts. Climate change education offers salient opportunities for teacher and students to consider cause and effect on many scales both geographic and temporal, and participants were often curious about how to extend their teaching to include regional effects that would be relevant to students' daily lives.

Teacher Learning of Pedagogical Practices for Teaching about Climate

In addition to learning important content, teachers indicated that participation in the Climate Academy allowed them to develop new ideas and understandings related to pedagogical practices for teaching about climate change. Most teachers (53 %), for example, reported increased familiarity with NGSS and how the new standards would influence curriculum and assessment. Kathy noted: "I learned how to read NGSS and became familiar with their progressions through the grades." Further, most teachers learned about new pedagogical practices supported by NGSS and expressed interest in implementing them in their classroom. Such activities included the use of data and models (59 %), the integration of web-based curricular and technological resources for teaching about climate change (70 %), and the use of formative assessment practices to understand student thinking of climate change (70 %) (see Table 3). Such activities have the potential to engage students with effective methods of inquiry that lead to greater understanding of scientific phenomena. Lydia, explained:

> I learned several pedagogical techniques to take back in my classroom around formative assessment and the use of models. I particularly enjoyed the carbon lifestyle calculations and the modeling of chemical structures. Even though my students are younger, they would benefit from examining molecular models and exploring beginning questions.

Nevertheless, teachers had remaining questions around the influence of NGSS on informal education, the alignment of NGSS with Common Core State Standards, and the development of NGSS-aligned lessons. Patti noted characteristically:

> I am still overwhelmed by how I'm going to teach the NGSS-related standards related to climate change. I'm confused by how to incorporate them in an organized way into my existing curriculum. Climate change definitely connects to each of my curriculum units, but I need more support in organizing climate change topics effectively across these units.

Application of New Learning in Teachers' Instructional Units

During the Academy, participants were provided opportunities to work in small groups to design 3- to 5-h instructional units on climate change for implementation

Table 3 Teacher learning of pedagogical practices for teaching about climate

Pedagogical issues	No. of teachers	Key sample excerpts from reflections	Remaining questions/required support
Greater understanding of NGSS	9 (53 %)	Gained a better understanding of NGSS and how I should look at them when developing a lesson	What is the connection between NGSS and Common Core [State] Standards?
			How do I unpack NGSS in order to create effective lessons for my students?
NGSS-aligned practices: data and models	10 (59 %)	I learned how to use models for conservation of matter and transformation of energy as powerful tools to illustrate these concepts to students	How do I incorporate topographic maps in order to help students understand watersheds?
		I learned three activities to model sea level rise and use real-world data to show the rate of sea level change	Access to lessons that incorporate NGSS-aligned practices
Use of technological and curricular resources	12 (70 %)	I learned about web resources that can be used to teach climate change	Need more time to review online resources
		The CLEAN Network site is perfect for use by students	
Formative assessment	12 (70 %)	Using formative assessments helps shape strategies to better address my students' needs	How to create NGSS-aligned assessments
		It is important to identify and address student misconceptions	

in their respective classrooms. In the design of their instructional unit, participants were encouraged to utilize content, pedagogical practices, and teaching resources presented during the Climate Academy. The majority of instructional units included a story line that began with the distinction between weather and climate, the definition of climate change, exploration of the mechanism of climate change using hands-on activities modeled in the Academy, and examination of how global changes can affect regional sea level rise around the Delmarva peninsula. A smaller number of instructional units encouraged students to consider mitigation and adaptation strategies for climate change on a local level. Table 4 provides an overview of the instructional units, illustrating the number of teachers who referenced specific content and pedagogy learned in the Climate Academy.

As shown in Table 4, all teachers addressed content related to human impacts of climate change (100 %), which was a key component of the Climate Academy. Bob and Nancy, for example, incorporated video-based resources and the Keeling curve animation to help students understand the connection between rising levels of carbon dioxide and increased temperatures over time. Additionally, most teachers incorporated content around climate change definition and evidence (94 %) and sea level rise (94 %). Ellen, for example, focused on helping students debunk common misconceptions around climate by using evidence and constructing graphic organizers that illustrated impacts of climate in relation to sea level rise.

Table 4 Representation of PD content and practices in teacher instructional units

PD element	Individual constructs	No. of teachers
Content	Human impacts and climate change	16 (100 %)
	Weather versus climate: definition and evidence	15 (94 %)
	Sea level rise: causes and impacts	15 (94 %)
	Carbon cycling (e.g., tracking carbon through the ecosystem)	9 (56 %)
	Mitigation and adaptation strategies for climate change	6 (37 %)
Pedagogy	Analyze and interpret data to illustrate climate changes	16 (100 %)
	Develop and use models: sea level rise	15 (94 %)
	Develop and use models: carbon cycle	4 (25 %)
	Develop and use models: combustion	4 (25 %)
	Identified and integrated technology resources for climate change topics	16 (100 %)
	Utilized formative assessments on student thinking of climate change	16 (100 %)
Local impacts	Utilized climate change content relevant to local impacts	16 (100 %)

Further, all teachers utilized strategies modeled during the Academy with the majority of them focusing on the use of data (100 %) and models (94 %) to illustrate climate changes. Rachel, for instance, a high school chemistry teacher worked with an informal teacher to design an instructional unit that engaged students in collecting field data on water quality in terms of level of dissolved oxygen, salinity, pH, turbidity, and temperature as well as air quality in terms of carbon dioxide levels and temperature. Subsequently, students were expected to develop models of water quality. This unit was specifically ascribing to NGSS weather and climate standards that specify student use of models to describe variation in energy flow into and out of the Earth's system ultimately resulting in climate changes. As shown in Table 4, however, most teachers focused on the use of models specific to sea level rise, while fewer teachers referenced models specific to the carbon cycle or combustion.

As shown in Table 4, to facilitate the implementation of new practices all teachers relied upon curricular and technological resources introduced in the Academy, particularly the resources available on the Climate Literacy & Awareness Network (CLEAN). This is particularly important because while NGSS outlines what students should know at each grade level, they do not identify specific curriculum materials that facilitate implementation in classroom practice. Finally, all teachers utilized formative assessment practices such as having students construct graphic organizers of their climate science understanding and identified connections between climate change and local impacts to make content relevant to their own context and students. Teachers in coastal areas, for instance, made such connections through sea level rise as a result of recent extreme weather events.

Presentation of Focal Case Study

In this section, we present a case study from a middle school teacher, Mr. Finley, to illustrate the connection between participation in the Climate Academy, teacher learning and practice, and initial outcomes on student beliefs toward climate change. Mr. Finley engaged in all PD activities and expressed interest early on to carry his new learning into practice. Mr. Finley's instructional unit addressed changes in the atmosphere due to human activity, focusing on the increase in carbon dioxide (CO_2) concentration and its impact on the environment and sea level rise.

Mr. Finley's Implementation of the Climate Change Instructional Unit

The overarching goal of the instructional unit designed by Mr. Finley was to help students understand that changes in the atmosphere due to human activity have increased CO_2 concentrations and thus affect climate. Mr. Finley launched his instructional unit by administering a formative assessment to activate students' prior knowledge. He then implemented a series of activities to help students understand how burning fossil fuels increases atmospheric CO_2 resulting in increased temperatures, the melting of the glaciers, and sea level rise. In particular, the students conducted experiments to (a) detect CO_2 made from the reaction of baking soda and vinegar using the chemical indicator bromothymol blue (BTB) and examine how the CO_2 levels vary with and without the presence of plants; (b) demonstrate that increased CO_2 levels cause air to heat faster than air with ambient CO_2 levels; and (c) determine how ice melt (sea vs. land) contributes to the volume of water (see Fig. 2). In addition, students built physical models to understand the molecular composition of baking soda and vinegar and to reconstruct the molecules after the resulting chemical reaction (see Fig. 2). Using data collected through their experiments, students discussed the effects of burning fossil fuels, the effects of deforestation, and how the levels of carbon dioxide in the air changed over the last few decades, as illustrated by the Keeling Curve—a graphical representation of data depicting the increase in CO_2 in earth's atmosphere over time. Discussing his decision for these activities Mr. Finley noted during his interview:

> The Keeling Curve had a big impact on my learning during the Climate Academy, clearly illustrating the connection of CO_2 and human behavior. Therefore, it seemed important to communicate this idea to the students because there is something we can do about it.

To further demonstrate the human impact on the levels of CO_2, Mr. Finley used a variety of resources from CLEAN introduced during the Academy, including a carbon footprint calculator to have students calculate their own carbon footprint. He noted:

> In the Climate Academy, we figured out our own [carbon] footprint and that had an impact on me. I had never thought about it that way before and I thought it would have an impact on my students.

In the last portion of the unit, Mr. Finley made the connection between increased levels of CO_2, temperature, the melting of the glaciers, and sea level rise. As he

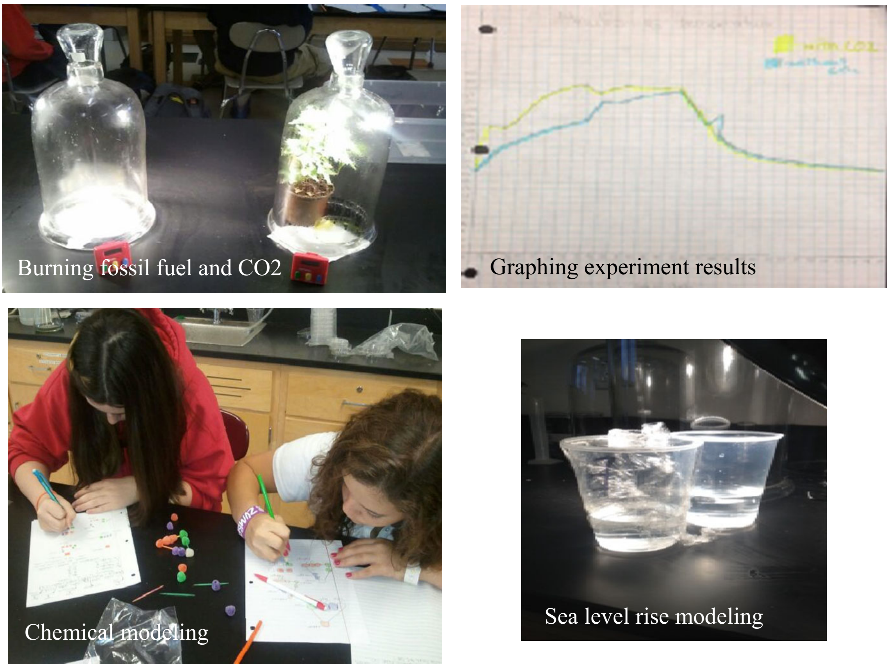

Fig. 2 Experimentation in Mr. Finley's classroom

noted, his school was close to the coast and thus was important for students to make immediate local connections to climate change.

In this case, Mr. Finley illustrated how participation in the Climate Academy influenced his own learning and thinking as well as classroom practice. Mr. Finley implemented content learned during the Academy while utilizing a variety of curricular and technological resources also introduced during the Climate Academy. Further, he implemented a number of pedagogical practices modeled in the Academy such as data analysis and modeling activities on carbon cycling and sea level rise. At the end of his unit Mr. Finley noted:

> I definitely grew in terms of content knowledge. I really didn't know much at all about climate change prior to the Academy, but it really got me thinking about it. It also helped me as a science teacher in general, because it forced me to use inquiry and technology in the classroom in ways I hadn't before. Going through that process first as a learner gave me confidence to guide the students through that process as well.

Student Outcomes: Beliefs Toward Climate Change

As a part of Mr. Finley's climate change instructional unit, students also responded to the *Six Americas* 15-item survey on beliefs and involvement toward climate change. Table 5 illustrates students' beliefs and thinking about climate change on the relevant Six Americas questions. Although survey responses

Table 5 Percentage of student responses to opinion questions

Question text	Pre (%)	Post (%)
1. Do you think global warming is happening?		
Yes	80.3	91.1
No	7.1	5.5
Don't know	12.6	3.4
2. Assuming global warming is happening, do you think it is		
Caused mostly by human activities	76.4	80.8
Caused mostly by natural changes in the environment	14.2	11.0
Other causes	3.1	2.7
None of the above because global warming isn't happening	6.3	5.5
3. How much do you think global warming will harm you personally?		
A great deal	5.5	7.5
A moderate amount	46.5	47.3
Only a little	1.6	1.4
Not at all	22.0	20.5
Don't know	24.4	23.3
4. When do you think global warming will start to harm people in the USA?		
In 10 years	18.9	20.5
In 25 years	16.5	19.2
In 50 years	20.5	31.5
In 100 years	29.1	17.8
Never	15.0	11.0
5. How much do you think global warming will harm future generations of people?		
A great deal	36.2	37.7
A moderate amount	37.0	43.8
Not at all	8.7	7.5
Don't know	18.1	11.0
6. How much had you thought about global warming before today?		
A lot	5.5	11.0
Some	25.2	31.5
A little	39.4	33.6
Not at all	29.9	24.0
7. How important is the issue of global warming to you personally?		
Extremely important	4.7	6.2
Very important	13.4	14.4
Somewhat important	38.6	41.8
Not too important	28.3	28.8
Not at all important	15.0	8.9
8. How worried are you about global warming?		
Very worried	5.5	11.0
Somewhat worried	39.4	45.2
Not very worried	36.2	31.6
Not at all worried	18.9	12.3

Table 6 Audience segmentation of students in *Six Americas* profiles

Profile type	No. of students pre-instruction (%)	No. of students post-instruction (%)
Alarmed	5 (3.9 %)	7 (4.8 %)
Concerned	28 (22.0 %)	42 (28.8 %)
Cautious	56 (44.1 %)	68 (46.6 %)
Disengaged	17 (13.4 %)	15 (10.3 %)
Doubtful	13 (10.2 %)	5 (3.4 %)
Dismissive	8 (6.3 %)	9 (6.2 %)

indicated that some students might have changed their beliefs and thinking regarding the causes, impacts, and importance of climate change, results were not statistically significant.

Analysis of survey data was also conducted to determine the segmentation of the students before and after Mr. Finley's instructional unit. All six profiles were found at both time points with the vast majority of students identified as *Concerned* or *Cautious* as illustrated in Table 6. The *Concerned* are less likely than the *Alarmed* to exhibit certainty that global warming is caused by humans or that future generations are at risk. Nevertheless, they are still much higher than all segments other than the *Alarmed* on all key beliefs. The *Cautious* are more likely to believe that global warming is happening, but they see it mostly as a problem for people in the future. The students' profile distribution before and after instruction was analyzed using a Mann–Whitney U test. This statistical test was chosen because the identified profiles (the dependent variable) are ranked in order of strength of belief and level of engagement with the issue of climate change. The Mann–Whitney U test determined there was no statistical significance between the pre- and post-instruction profile distributions ($U = 8095.5$, $z = -1.918$, $p = 0.055$).

Discussion and Implications

As states adopt and implement the NGSS, a shift is taking place in terms of developing the content knowledge and pedagogical skills of teachers. This is particularly the case with content areas such as climate science, that received limited curricular attention in years past (NGSS Lead States, 2013). As a result, little is known about how to best support students' learning of climate science, and few PD programs are in place to support teachers' needs (Johnson et al., 2008; Shepardson et al., 2012). In this work, we examined a PD design intended to help teachers learn about climate change, a topic included for the first time in US standards. Drawing on core principles of environmental PD, our work indicates that a focus on the science of climate change and modeling of theoretically driven pedagogical activities can help teachers improve their climate science knowledge as well as their understanding of how to teach climate science concepts by aligning content and practices with students' local environment (Sondergeld et al., 2014).

This finding is consistent with prior literature that emphasizes the need to help teachers increase their content knowledge of earth systems and pedagogical understanding of how to convey its relevance to their students (Ellins et al., 2014).

Findings from this work indicated that all teachers appreciated the opportunity to learn important content from climate experts and experience hands-on modeling during the summer institute. The design of the PD strived to connect climate science knowledge development, pedagogical practices, and outdoor applications as suggested in the research literature. This model proved successful in supporting teachers' effectiveness at developing lessons for their students that focused on climate change. Further, most participants planned on implementing a variation in the activities modeled during the Academy in their classroom as indicated in their instructional units. Nevertheless, our work did not document whether and how participating teachers implemented those units in their classrooms.

Additionally, findings from our focal case study indicated that implementation of climate change instructional units that focus on both content knowledge and practices advocated in the new standards (e.g., rich open-ended tasks, evidence, and data supporting conclusions around climate change) can begin to initiate a shift in student beliefs. After experiencing an instructional unit designed during the Academy, students in Mr. Finley's classroom expressed more certain views that climate change is happening, including its potential impacts on them personally and on future generations of humans. Further, they increased in their awareness and involvement around issues of climate.

Despite the positive connections among the Climate Academy, teacher learning, and student beliefs, teachers' reflections continued to identify areas requiring further development in their content knowledge as well as understanding of how to infuse climate content with existing curricula and resources. These difficulties can be explained by interdisciplinary nature of climate science, making it a challenging topic to teach and learn since a broad knowledge base is required for comprehension (NRC, 2012; Shepardson et al., 2012). These findings suggest that PD programs should be ongoing and support teachers' learning over time. As with this Academy, teachers met almost monthly over the course of a year to discuss focus topics, develop lessons, and address concerns in a learning community. Establishing a network of teachers that support one another's learning is critical for the implementation of successful curricula in topics that teachers are not necessarily familiar with or accustomed to teaching (Luft & Hewson, 2014). Similar to the addition of climate change in the new standards, other more familiar science topics are also explicated in greater detail than ever before within NGSS. Yet, as seen in this study, teachers will require greater support to understand not only the science content that aligns with NGSS but also the pedagogical crosscutting practices that support student learning.

Additionally, participants expressed needs for ongoing support in their ability to adapt content and pedagogical materials modeled during the Climate Academy with younger or older groups than those originally intended by the Academy presenters and differentiate their instruction for their current students. Similarly, science content areas that are new or further refined by NGSS may also require greater exposure to content ideas over many grades. Future Academies need to address this challenge by providing pedagogical suggestions for how to adapt both content presentation and modeling activities for different grade levels.

Findings also indicated that an overwhelming number of participants remained concerned about their ability to integrate climate change with their local curriculum. Although both Maryland and Delaware adopted the NGSS where climate change is included in earth science, implementation timelines vary, creating challenges for participants in navigating existing curricula requirements in light of state policies. Both the virtual and face-to-face follow-up meetings provided participants with resources, support, and a community of like-minded educators intended to help them navigate state policies while preparing for the implementation of NGSS. Yet, not all participants maintained consistent participation in the follow-up meetings. Future Climate Academies will benefit from added incentives that help maintain consistent and long-term teacher participation in PD, to ensure positive changes in learning, instructional practice, and student outcomes.

In future iterations of the Climate Academy, we also intend to cover social and economic factors associated with climate change, an issue that was not addressed in the current Climate Academy. Although NGSS performance expectations specific to climate change do not overtly stipulate understanding of socioeconomic impacts of a changing climate, we feel that these impacts are critical for students to understand as they consider mitigation and adaptation strategies around climate change. In particular, students will be required to think deeply about topics such as food and water scarcity, land use, as well as economic and policy issues impacted by a changing climate. It is imperative to extend our PD supports to include these topics and demonstrate how teachers may present complex perspectives relevant to the socioeconomic impacts of climate change with their students.

As more states begin and continue NGSS implementation, systematic PD will be required to support best practices in teacher education—in terms of both content knowledge and pedagogy relevant to the new standards. As with the Academy, teacher education about NGSS will take time and repeated exposure to new ideas and the generation of learning communities. We will continue offering the Climate Academy to middle school, high school, and informal educators who interact with students in these grade bands. NGSS specifies climate change science as relevant to both middle and high school students, thus making it necessary for all science teachers at those grade levels to integrate climate science content in their respective curricula. We will also continue our research into PD designs that promote teacher engagement and learning with climate change, including the benefits of participation in learning communities, such as the one generated by MADE CLEAR.

Conclusion

As adoption of NGSS increases across the USA and implementation plans are defined, future research must take a closer look at what constitutes effective teacher support for implementation of climate-related content and student outcomes, not only in terms of beliefs around climate change but also in terms of content understanding as well as behaviors (Holthuis et al., 2014). For example, how does content presentation and open-ended hands-on tasks impact student understanding of the causes, mechanisms, and impacts of climate change? What is the role of online simulations in student reasoning around climate change? What types of pedagogical practices influence students' interest, concern, and age-appropriate behaviors around climate change? Findings to these questions are fundamental for preparing future generations who think critically about climate change claims, predictions, and models. Keeping an eye on student outcomes and practices is critical for understanding how a content area new to science education can be effectively conveyed to students. It is likely that other standards outside the realm of earth science will experience similar requirements for assessment. In the meantime, lessons learned from projects such as the one presented in this study, demonstrate that with ongoing supports that emphasize content learning, pedagogical supports, and place-based relevance, teachers can encourage student learning about climate change science in meaningful ways that promote deeper understanding of Earth's changing climate.

References

Andersson, B., & Wallin, A. (2000). Students' understanding of the greenhouse effect, the societal consequences of reducing CO_2 emissions and the problem of ozone layer depletion. *Journal of Research in Science Teaching, 37*, 1096–1111.

Barnett, M., Houle, M., Mark, S. L., Minner, D., Hirsch, L., Strauss, E., … Hufnagel, B. (2014). Participatory professional development: Geospatially enhanced urban ecological field studies. In J. MaKinster, N. Trautmann, & M. Barnett (Eds.), *Teaching science and investigating environmental issues with geospatial technology: Designing effective professional development for teachers* (pp. 13–33). New York, NY: Springer.

Bogdan, R. C., & Biklen, S. K. (2003). *Qualitative research for education: An introduction to theories and methods* (4th ed.). New York, NY: Pearson.

Boyes, E., & Stanisstreet, M. (1993). The greenhouse effect: Children's perception of causes, consequences, and cures. *International Journal of Science Education, 15*, 531–552.

Boyes, E., & Stanisstreet, M. (1994). The idea of secondary school children concerning ozone layer damage. *Global Environmental Change, 4*(5), 311–324.

Boyes, E., & Stanisstreet, M. (1997). Children's models of understanding of two major global environmental issues (ozone layer and greenhouse effect). *Research in Science and Technology Education, 15*, 19–28.

Boyes, E., & Stanisstreet, M. (2001). Plus ça change, plus c'est la même chose? School students' ideas about the "greenhouse effect" a decade on. *Canadian Journal of Environmental Education, 6*(1), 77–101.

Dupigny-Girouz, L. L. (2010). Exploring the challenges of climate science literacy: Lessons from students, teachers and lifelong learners. *Geography Compass, 4*, 1203–1217.

Ellins, K. K., Ledley, T. S., Haddad, N., McNeal, K., Gold, A., Lynds, S., & Libarkin, J. (2014). *EarthLabs*: Supporting teacher professional development to facilitate effective teaching of climate science. *Journal of Geoscience Education, 62*, 330–342.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and its impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 51–94). Dordrecht, The Netherlands: Kluwer.

Gowda, M. V. R., Fox, J. C., & Magelky, R. D. (1997). Students' understanding of climate change: Insights for scientists and educators. *Bulletin of the American Meteorological Society, 78*(1), 2232–2240.

Herman, J. (2013). *Formative assessment for Next Generation Science Standards: A proposed model*. Princeton, NJ: K-12 Center at ETS. Retrieved from http://www.k12center.org/rsc/pdf/herman.pdf.
Hestness, E., McGinnis, J. R., Riedinger, K., & Marbach-Ad, G. (2011). A study of teacher candidates' experiences investigating global climate change within an elementary science methods course. *Journal of Science Teacher Education, 22*, 351–369.
Hirabyashi, J. (2011). *CLEAN pathways informant survey #1*. Inverness, CA: Inverness Research Associates. Retrieved from http://www.corestandards.org/.
Hodson, D. (2013). Don't be nervous, don't be flustered, don't be scared: Be prepared. *Canadian Journal of Science, Mathematics and Technology Education, 13*, 313–331.
Holthuis, N., Lotan, R., Saltzman, J., Mastrandrea, M., & Wild, A. (2014). Supporting and understanding students' epistemological discourse about climate change. *Journal of Geoscience Education, 62*, 374–387.
Intergovernmental Panel on Climate Change [IPCC]. (2013). Climate change 2013: The physical science basis. In T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.), *Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY: Cambridge University Press. Retrieved from http://www.climatechange2013.org/report/full-report/.
Jickling, B. (2001). Climate change, global warming, and education with uncertainties. *Canadian Journal of Environmental Education, 6*(1), 5–7.
Johnson, R. M. (2011). *National earth science teachers' association survey of the needs and concerns of K-12 earth and space science educators*. Retrieved from http://www.nestanet.org/cms/sites/default/files/documents/ExecutiveSummaryClimateChangeEducationSurveyDecember2011.pdf.
Johnson, R. M., Henderson, S., Gardiner, L., Russell, R., Ward, D., Foster, S., … Eastburn, T. (2008). Lessons learned through our climate change professional development program for middle and high school teachers. *Physical Geography, 29*, 500–511.
King, M., Shearon, E. L., Burgette, J. E., & Sivin-Kachala, J. (2012). *Teaching climate change: Cumulative summary for the evaluation of PBS Teacher Line's NASA Innovations in Climate Education online professional development*. Retrieved from http://wwwtc.pbs.org/teacherline/courses/common_documents/research/pbs-cumulative-summary-final.pdf.
Kirk, K. (2011). *Teaching environmental issues and the affective domain*. Retrieved from http://serc.carleton.edu/NAGTWorkshops/affective/environment.html.
Kubitskey, B. (2006). *Extended professional development for systemic curriculum reform* (Unpublished doctoral dissertation). University of Michigan, Ann Arbor, MI.
Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education* (pp. 889–909). New York, NY: Routledge.
Lynds, S. (2009). *Inspiring climate education excellence program needs assessment survey report*. Boulder: CIRES Education and Outreach, University of Colorado. Retrieved from http://cires.colorado.edu/files/9013/9577/9211/EO-ICEENeedsAssessmentReport.pdf.
Maibach, E., Leiserowitz, A., Roser-Renouf, C., Mertz C. K., & Akerlof, K. (2011). *Global warming's Six Americas screening tools: Survey instruments; instructions for coding and data treatment; and statistical program scripts*. Yale University and George Mason University. New Haven, CT: Yale project on Climate Change Communication. Retrieved from http://climatechangecommunication.org/SixAmericasManual.cfm.
Maibach, E. W., Leiserowitz, A., Roser-Renouf, C., & Mertz, C. K. (2011b). Identifying like-minded audiences for climate change public engagement campaigns: An audience segmentation analysis and tool development. *PLoS One, 6*(3), e17571. doi:10.1371/journal.pone.0017571.
Maibach, E., Roser-Renouf, C., & Leiserowitz, A. (2009). *Global warming's Six Americas 2009: An audience segmentation*. New Haven, CT: Yale Project on Climate Change Communication. Retrieved from http://www.climatechangecommunication.org/images/files/GlobalWarmingsSixAmericas2009c.pdf.
McGinnis, J. R., & Simmons, P. (1999). Teachers' perspectives of teaching science–technology–society in local cultures: A sociocultural analysis. *Science Education, 83*, 179–212.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage.
National Research Council [NRC]. (2012). *Climate change education in formal settings, K-14: A workshop summary*. Washington, DC: The National Academies Press.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.
Pruneau, D., Gravel, H., Courque, W., & Langis, J. (2003). Experimentation with a socio-constructivist process for climate change education. *Environmental Education Research, 9*, 429–446.
Pruneau, D., Moncton, U., Liboiron, L., & Vrain, E. (2001). People's ideas about climate change: A source of inspiration for the creation of educational programs. *Canadian Journal of Environmental Education, 6*(1), 58–76.
Roehrig, G., Campbell, K., Dalbotten, D., & Varma, K. (2012). CYCLES: A culturally-relevant approach to climate change education in native communities. *Journal of Curriculum and Instruction, 6*, 73–89.
Sadler, T. D., Amirshokoohi, A., Kazempour, M., & Allspaw, K. M. (2006). Socioscience and ethics in science classrooms: Teacher perspectives and strategies. *Journal of Research in Science Teaching, 43*, 353–376.
Schmidt, W. H. (2001). Defining teacher quality through content: Professional development implications from TIMSS. In J. Rhoton & P. Bowers (Eds.), *Professional development planning and design* (pp. 141–164). Arlington, VA: National Science Teachers Association and National Science Education Leadership Association.
Shepardson, D. P., & Niyogi, D. (2012). *An earth system science teacher professional development tool kit for climate science*. West Lafayette, IN: Purdue University. Retrieved from http://iclimate.org/ccc/edu/static/workingMANUAL.pdf.
Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2009). Seventh grade students' conceptions of global warming and climate change. *Environmental Education Research, 15*, 549–570.
Shepardson, D. P., Niyogi, D., Roychoudhury, A., & Hirsch, A. (2012). Conceptualizing climate change in the context of a climate system: Implications for climate and environmental education. *Environmental Education Research, 18*, 323–352.
Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1–22.
Sondergeld, T. A., Milner, A., & Rop, C. (2014). Evaluating teachers' self-perceptions of their knowledge and practice after participation in an environmental education professional development program. *Teacher Development: An International Journal of Teachers' Professional Development, 18*, 281–302.
Wise, S. B. (2010). Climate change in the classroom: Patterns, motivations, and barriers to instruction among Colorado science teachers. *Journal of Geoscience Education, 58*, 297–309.
Yale/George Mason. (2009). *Global warming's Six Americans: An audience segmentation analysis.* Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change. Retrieved from http://environment.yale.edu/climate-communication/files/climatechange-6americas.pdf.