Title: Science Teacher Professional Development and Climate Change Education in the Context of the Next Generation Science Standards

Short title: Teacher Professional Development and Climate Change Education

Authors:
Emily Hestness[1], R. Christopher McDonald[1], Wayne Breslyn[1], J. Randy McGinnis[1], and Chrystalla Mouza[2]
[1]*Department of Teaching and Learning, Policy and Leadership, University of Maryland - College Park*
[2]*School of Education, University of Delaware*

Corresponding Author:
Emily Hestness
Department of Teaching and Learning, Policy and Leadership
College of Education
2311 Benjamin Building
University of Maryland
College Park, MD 20742-1115
hestness@umd.edu
Telephone: 202-271-8625
Fax: 301-314-9055

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Abstract
The Next Generation Science Standards (NGSS) are the first set of U.S. national science standards to explicitly include the topic of global climate change. With this new emphasis on climate change in K-12 science education, geoscience educators will likely play a central role in shaping a nation of citizens capable of understanding and making informed decisions about global climate change. In charting a path forward, it is timely to consider the ways in which geoscience educators can be effectively prepared and supported as climate change education leaders. In this article, we analyze the inclusion of climate change in the Next Generation Science Standards, and review existing literature on professional development related to climate change education. Next we present several insights, emphasizing: 1) the potential of regional observations-focused learning progressions for making climate change personally relevant to learners; 2) the need for quality standards-aligned curricular resources to support climate change instruction, especially those that integrate technology; and 3) the value of research-based professional development and teacher education for advancing climate change education.

Key words: Climate change education, science teacher education, Next Generation Science Standards, learning progressions

INTRODUCTION

Current climate literacy efforts are situated at the crossroads of significant sociopolitical, educational, and environmental change. Scientific evidence points to a warming world accompanied by rapid and widespread global change (IPCC, 2007), and many Americans are beginning to directly observe potential climate change impacts in their own communities (NCADAC, 2013). In the realm of science education, the salience of climate change became particularly evident with the recent release of the Next Generation Science Standards (Achieve Inc., 2013), the first set of U.S. national science standards to explicitly include the topic. Yet despite increased awareness of global climate change amongst the American public and in U.S. schools, relatively few students possess the kinds of sophisticated scientific understandings regarding climate change that will enable them to fully participate in society as environmentally literate decision-makers (Mohan, Chen, & Anderson, 2009; Jin & Anderson, 2012). This imbalance between personal concern and scientific literacy underscores the need for science educators prepared to teach about the science of climate change and its impacts.

The release of the final version of the NGSS on April 9, 2013, " a new set of voluntary, rigorous, and internationally benchmarked standards for USA K-12 science education" (Achieve, 2013, para. 1), has garnered increased attention for climate change education. Because standards have considerable influence on classroom instruction (Wise, 2010), the NGSS have the potential to catalyze climate change education efforts over the coming years. Table 1 provides examples of Performance Standards from the NGSS in which the concept of climate change is overtly stated. The examples are taken from the domain of Earth Science, the only content area within the NGSS in which climate change is explicitly mentioned. While the topic does not directly appear in the physical or life sciences standards in the NGSS, standards in these disciplines do address constructs relevant to climate change (e.g., relationships among energy transfer, type of matter, and temperature in physical science (MS-PS3-4); maintaining biodiversity and ecosystem services (MS-LS2-5)).

Performance Standards		
Code[1]	**Standards**	**Clarification Statement & Assessment Boundary**
HS-ESS3-1	Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.	Examples of key natural resources include access to fresh water (such as rivers, lakes, and groundwater), regions of fertile soils such as river deltas, and high concentrations of minerals and fossil fuels. Examples of natural hazards can be from interior processes (such as volcanic eruptions and earthquakes), surface processes (such as tsunamis, mass wasting and soil erosion), and severe weather (such as hurricanes, floods, and droughts). Examples of the results of changes in climate that can affect populations or drive mass migrations include changes to sea level, regional patterns of temperature and precipitation, and the types of crops and livestock that can be raised.
HS-ESS2-4	Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.	Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition. Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.
HS-ESS3-4	Evaluate or refine a technological solution that reduced impacts of human activities on natural systems.	Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).
HS-ESS3-5	Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.	Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition). Assessment is limited to one example of a climate change and its associated impacts.

TABLE 1. SAMPLE NGSS HIGH SCHOOL PERFORMANCE STANDARDS RELEVANT TO CLIMATE CHANGE EDUCATION

[1]For a key to NGSS acronyms, see: http://www.nextgenscience.org/next-generation-science-standards

Despite positive advances towards making climate change a meaningful part of K-12 science instruction, major challenges remain. First, climate change continues to be recognized as a potentially sensitive topic in the U.S. due to ongoing political debate and stated resistance by some vociferous skeptics. Second, as a socioscientific issue, or open-ended and unresolved science-related problem affecting society, addressing climate change in the classroom may also involve addressing its potentially challenging moral and ethical dimensions (Zeidler & Keefer, 2003; Sadler & Zeidler, 2005; Sadler, 2011). Science teachers have traditionally viewed these aspects of socioscientific issues as problematic to address in the classroom and outside the realm of their roles as science teachers (McGinnis, 2003). A final limitation related to climate change education is the topic's placement in the NGSS. In the high school level standards, the topic is located only within the discipline of Earth Science (see Table 1). This placement is problematic because presently, many U.S. students do not take Earth Science in high school (McNeal, 2010). While this is a challenge, the positioning of climate change in the Earth Sciences creates the potential for a renewed emphasis on the geosciences in science education.

All of these challenges raise critical questions about appropriate educational responses to climate change. Various initiatives, including the National Science Foundation's Climate Change Education Partnership (CCEP) program, seek to create an infrastructure that would help educators address these issues. The purpose of this article is to report on work situated in the context of a CCEP-funded project, Maryland and Delaware Climate Change Education, Assessment, and Research (MADE CLEAR, www.madeclear.org). The project focuses on the implementation of a comprehensive climate change education plan for our region, that involves collaboration between formal and informal science educators, climate scientists, public mass communication outlets, and science education researchers. The project addresses climate change education through the lens of regional observations (NCADAC, 2013), with the goal of supporting learners in constructing explanations about climate change relevant to their own lives and communities.

We report specifically on ways in which MADE CLEAR will address teacher preparation and professional development in the area of climate change. We begin by presenting a literature review that outlines key insights from past studies of teacher preparation and professional development in climate change education. Specifically, we focus on teachers' climate change content and pedagogical knowledge, their interactions with climate change curricular resources and technologies, and the pressures they face in bringing climate change into the classroom. We follow the literature review with a description of our own approach to teacher learning and climate change education.

REVIEW OF THE LITERATURE

Learning to Teach Complex Climate Science Content

In preparing students to make scientifically informed decisions related to climate change, teachers must be able to address complex scientific constructs. These include topics such as the relationship between greenhouse gases and radiation in the atmosphere, the effects of fossil fuel combustion on atmospheric greenhouse gas concentrations, and the ways in which the enhanced greenhouse effect influences the earth's energy balance (Ekborg & Areskoug, 2006). Teachers must also have an understanding of future projections related to climate change impacts, how climate models are developed and interpreted, and issues of uncertainty in climate science. Further, they need to understand the natural and anthropogenic factors related to climate change, anticipated consequences of increasing global temperatures, and potential approaches to climate change mitigation and adaptation (Lambert, Lindgren, & Bleicher, 2012).

While some science teachers have extensive knowledge in these areas, many teachers report that they feel underprepared in their science content backgrounds to fully address climate change science in their classrooms. Wise (2010) noted that few teachers take college-level courses related to climate science, and generally report learning about climate change on their own. As a result, teachers may derive environmental knowledge from media sources that do not reflect a scientific viewpoint (Michail, Stamou, & Stamou, 2007), or that portray climate science as highly controversial (Lambert et al., 2012). While formal opportunities for teachers to learn about climate change may improve their understanding of the relevant science, teachers may not necessarily develop highly sophisticated understandings from such experiences (Ekborg & Areskoug, 2006). An additional challenge relates to teachers' disciplinary backgrounds. Even science teachers with advanced science degrees may not feel confident with science content outside their areas of expertise. For example, many biology teachers state that they do not feel well prepared to teach about climate-related topics (NRC, 2012).

A number of climate change misconceptions (also referred to as alternative conceptions) among teachers have repeatedly emerged in the literature (see Table 2). Most commonly reported has been the belief that ozone layer depletion is a cause of global warming. Other areas of confusion relate to the greenhouse effect, including the belief that it is an environmental problem rather than a natural phenomenon. Researchers have also documented misconceptions around the carbon cycle, how greenhouse gases enhance the greenhouse effect, and the distinction between climate and weather. The recurrence of such misconceptions raises questions about whether teachers run the risk of communicating scientifically inaccurate climate change information to their students.

Misconception	Study
Global warming is caused by a hole in the ozone	Ekborg & Areskoug, 2006; Lambert, Lindgren, & Bleicher, 2012; Dove, 1996; Wise, 2010; Papadimitriou, 2004; Michail, Stamou & Stamou, 2007; Matkins & Bell, 2007; Hestness, et. al, 2011)
Global warming causes skin cancer	Ekborg & Areskoug, 2006; Groves & Pugh, 1999; Dove, 1996; Michail, Stamou & Stamou, 2007
The greenhouse effect is caused by a lid or blanket that traps heat	Ekborg & Areskoug, 2006; Lambert, Lindgren, & Bleicher, 2012; Dove, 1996; Papadimitriou, 2004
The carbon cycle acts like a filter that cleans the air	Lambert, Lindgren, & Bleicher, 2012
Confusion about weather vs. climate	Lambert, Lindgren, & Bleicher, 2012; Papadimitriou, 2004
Greenhouse gases are “trapped” in the atmosphere	Lambert, Lindgren, & Bleicher, 2012
Global warming will cause decreased precipitation (drier conditions) in all locations	Dove, 1996
Global warming will enhance photosynthesis through increased solar radiation	Dove, 1996
Climate change is controversial in the scientific community	Wise, 2010; Matkins & Bell, 2007
Increasing the greenhouse effect would increase earthquake frequency	Groves & Pugh, 1999
Global warming is caused by increased solar radiation	Groves & Pugh, 1999
Using unleaded gasoline can reduce the greenhouse effect	Groves & Pugh, 1999
Nuclear power or weapons contribute to the greenhouse effect as much as coal power	Groves & Pugh, 1999; Papadimitriou, 2004
Environmental pollution generally causes global warming	Papadimitriou, 2004
Acid rain causes global warming	Papadimitriou, 2004; Groves & Pugh, 1999
The greenhouse effect is unnatural	Michail, Stamou & Stamou, 2007; Matkins & Bell, 2007

TABLE 2. SAMPLE CLIMATE CHANGE MISCONCEPTIONS FOR TEACHERS REPORTED IN THE LITERATURE

Other research has indicated a belief among teachers that there is no scientific consensus on climate change. Wise (2010) found that many of the teachers she surveyed “agreed” or “somewhat agreed” that there is substantial scientific disagreement about the cause of recent warming. To address this belief, researchers have suggested the importance of making climate change data accessible so that teachers and students can utilize it to draw evidence-based conclusions. They have also emphasized the need for increasing teachers' content knowledge and understandings of the nature of science (NRC, 2012).

Curriculum and Instruction Challenges in Climate Change Education

Despite scientific consensus on the existence and causes of accelerated global climate change, the topic has frequently been reported as controversial (McGinnis & McDonald, 2011). This has prompted debate over how climate change should be presented in schools, similar to other topics perceived as controversial, such as evolution and sex education. Such debates, which vary by community, present a challenge for science educators in navigating climate change in the classroom. To deal with the topic in a fair and unbiased manner, many teachers have thought that the best solution is to "teach both sides" of the issue, as if there exists another side to a scientific topic that holds a consensus scientific position. In Wise's (2010) survey of 628 Colorado science teachers, 85% believed that teachers should discuss both sides of the climate change public controversy (i.e., the debate over whether or not climate change is caused by humans) with students. Wise organized teachers' responses along a continuum consisting of three general viewpoints. On one end of the continuum (25% of the sample), was the belief that while students may discuss both sides in the science classroom, it is important for teachers and curricula to emphasize the scientific consensus on anthropogenic climate change. The middle 50% of teachers believed that teaching both sides is the fairest approach and can help to promote students' critical thinking and independent decision-making. At the opposite end of the continuum (the remaining 25% of the sample), teachers believed that both sides were equally scientifically valid and should both be taught.

While it is important to note that Wise's (2010) sample consisted of voluntary survey responses and may not represent the greater population of U.S. teachers, the results do demonstrate the spectrum of beliefs teachers may hold related to climate change pedagogy. They also relate to issues of teachers' content knowledge and views of the nature of science. Without strong understandings in these areas, teachers may be "vulnerable to counterclaims from sources devoted to disproving that climate change is occurring or is caused by human activity" (NRC, 2012, p. 38). Or, they may view and present claims in the classroom that are at odds with scientifically agreed upon understandings.

Policymakers at state and local levels may also have influence on teachers' approaches to the topic. Reardon (2011) described how teachers in one school district were required to demonstrate how they were handling issues formally defined as "controversial", such as climate change, in a "balanced" fashion. In states where climate change is also legally listed as a "controversial" topic, laws may dictate that teachers and students can challenge the topic in the classroom without fear of reprisal (Reardon). Policy conversations regarding the teaching of climate change have proliferated with the release of the NGSS. Teachers may fear the repercussions of their pedagogical choices, often related to responses of parents, school administrators, and school boards. A survey of 800 National Earth Science Teachers Association (NESTA) members likewise indicated that climate change, after only evolution, was most likely to trigger protests from parents and administrators (Reardon).

In navigating the sensitive nature of the climate change topic, teachers have been observed to employ a variety of strategies. Some of these, such as treating tensions that arise in the classroom as "teachable moments", using inquiry-based pedagogy, and inviting outside experts—such as climate scientists—to discuss the issue, are similar to strategies that teachers have used to address controversies related to evolution in the classroom (NRC, 2012). Johnson et al. (2011) found that while it is becoming less necessary to spend time "proving" that climate change is occurring, it is important to use data in the forms of climate change observations and model results so that students and teachers gain a better understanding of the practice of climate science. Science educators and researchers have argued that teachers must model the practices of science by engaging students in taking measurements, making observations, and making connections with the ongoing research in which climate scientists are engaged (NRC, 2012). They also argue that it is beneficial to student understanding of climate change when teachers connect local changes to changes in the larger global system. Matkins and Bell (2007) found that focusing on the nature of science was helpful for preservice teachers in terms of pedagogical decision-making related to climate change. However, this approach may also perpetuate teachers' views that they should address all perspectives on the issue, because, as one participant noted, "science isn't always exact" (p. 155).

Many science educators attempt to circumvent controversial moments in the classroom by focusing on "the facts" and keeping ideology and politics out of the classroom (Johnson et al., 2011). However, others interested in climate change as a socioscientific issue (SSI) argue the need for "contemporary school science that goes beyond teaching isolated factoids of scientific knowledge and fundamental skills", suggesting that "students should be able to respond sympathetically and responsibly to global issues tempered by their own sense of dignity, character, and values" (Lee, Chang, Choi, Kim, & Zeidler, 2012, p. 927). Hodson (2003) argued for a "much more overtly politicized form of science education" (p. 653), in which becoming scientifically literate means that students are capable of and committed to taking action on socioscientific issues like global climate change. Approaching climate change as a socioscientific issue with scientific, political, economic, and moral/ethical overlays provides a more authentic representation of climate change as a "real world" issue about which students must be prepared to make decisions as citizens.

These issues bring to light key questions of curricular inclusion. More than a decade ago, Fortner (2001) asked of climate change in schools, "Where does it fit and how ready are we?". These questions remain relevant. A primary reason that teachers avoid teaching climate change is a real or perceived lack of alignment between the topic and the content standards they teach (NRC, 2012). Wise (2010) found that in Colorado, high school Earth Science teachers were most likely to teach about climate change because of its relevance to their content standards. However, as discussed earlier, a minority of high school students take Earth Science at the high school level (McNeal, 2010). Teachers in other science disciplines, such as biology, perceive climate change to fall outside of their standards (Wise). Further, while many teachers agree that climate change concepts should be taught beyond the earth science and environmental science classrooms, teachers in other science domains may feel less prepared to address the topic (NRC, 2012). Such problems associated with curricular compartmentalization have prompted some to argue for a re-imagining of science education in the climate change era, and for moving away from the traditional discipline-based approach to science teaching (Sharma, 2012). Presently, however, under most existing curriculum models, teachers interested in addressing climate change are tasked with finding ways to fit it in to their already dense standards-based curricula.

Presenting Climate Change Education in Pre-Service Science Teacher Education

Studies in teacher education and professional development provide findings for effectively incorporating the climate change topic in the context of the NGSS. A number of teacher educators have described their experiences working with pre-service teachers on climate change education (Hestness, McGinnis, Riedinger, & Marbach-Ad, 2011; Matkins & Bell, 2007; McGinnis, Hestness, & Riedinger, 2011; Lambert et al., 2012; Ekborg & Areskoug, 2006). These studies and others suggest that interventions in pre-service teachers' science content and science methods courses can improve teachers' preparedness to address climate change in the classroom.

Recognizing that teachers may have similar misconceptions to their students, Ekborg and Areskoug (2006) involved preservice teachers in Sweden in two science content courses on the greenhouse effect, both of which were designed to address common misconceptions. By the end of the courses, they noted fewer misconceptions than had been reported in previous studies (e.g., Boyes & Stannisstreet, 1992), suggesting that the courses' design—which attended specifically to common alternative conceptions—was successful in helping teachers improve their understanding of climate change and the greenhouse effect. Other sources have suggested the use of alternative conceptions as a starting point for lessons, especially if they are not likely to be perceived as controversial. Addressing these first can prepare teachers to address other, potentially more sensitive, alternative conceptions later on (NRC, 2012). Also with regard to course design, Ekborg and Areskoug highlighted the importance of making connections between courses within teacher preparation programs, so that pre-service teachers can build on understandings from one course to the next. Finally, they suggested that teachers need guidance in connecting scientific knowledge to real-life situations.

Other studies offer insights into addressing climate change while future teachers are being prepared to teach science in science methods courses required for teacher certification (Hestness et al., 2011; Matkins & Bell, 2007; Lambert et al. 2012). Lambert et al. infused a climate change curriculum into an elementary science methods course. They measured changes in pre-service teachers' knowledge of climate change using their Knowledge of Global Climate

Change (KGCC) instrument, and found that participants significantly increased their knowledge of climate change. However, they also note that some students demonstrated problematic alternative conceptions even after the intervention, and call for the continued development of tools that can help reveal and identify teachers' alternative conceptions related to climate change.

In addition to gains in content knowledge, other studies examining the exploration of climate change in pre-service education have reported evidence of teachers' increased interest and confidence related to climate change (e.g., Hestness et al., 2011), and the development of more positive views on the nature of science and climate change (e.g., Matkins & Bell). Like Lambert et al. (2012), Matkins & Bell (2007) studied an instructional intervention on climate change in an elementary science methods course. Their approach included specific instruction on the nature of science, situated within issues related to climate change. Matkins and Bell found significant changes in participants' pre-instruction to post-instruction views of the nature of science and climate change. They argued for the value of "explicit, contextualized nature of science instruction" to support pre-service teachers in understanding the complex issues surrounding climate change. They also believed that this increased knowledge of the nature of science would have a positive impact on decision-making on socioscientific issues like climate change. While recognizing the tentative and evolving nature of scientific knowledge, experiences learning about climate change within a teacher education setting can help preservice teachers become more comfortable with the notion of using available scientific understandings in their decision-making—a key skill for scientifically and environmentally literate citizens.

In our study of integrating climate change into an elementary science methods course, we observed that an intervention conducted over a two week period that was informed by data collection by teacher candidates in their professional development schools and guided by current recommendations for active learning had the potential to significantly increase their sense of preparedness to teach about climate change (Hestness et al. 2011; McGinnis et al. 2011). However, we posited that teacher candidates need longer-term study of relevant science content outside of teaching methods courses. We also saw value in allowing teacher candidates opportunities, through journaling and discussion, to develop their own views about climate change education and its relevance to their future roles as science teachers. Pedagogically, we found that in modeling the kinds of activities teacher candidates could use to address climate change in their own classrooms (e.g., integrating current events, examining authentic data, engaging in scientific argumentation), it was important to involve the teacher candidates in explicit conversations about strategies being employed and how these might translate to their teaching contexts.

Presenting Climate Change in Professional Development for Practicing Teachers

Professional development activities with practicing teachers can also provide useful insights for future directions for preparing teachers to integrate climate change into their classroom instruction. Yet, little has been published to date on professional development approaches specific to climate change education.

As part of a large scale instructional intervention research, examining elementary students' science knowledge and awareness of social activism with regard to greenhouse effect and global warming, Lester, Ma, Lee, & Lampert (2006), offered professional development aimed at helping participating teachers implement a climate change education unit entitled the Living Planet. The professional development consisted of four full day workshops on regular school days throughout the year using an inquiry-based model as the instructional approach. The first three workshops focused on providing teachers with an opportunity to practice the unit lessons so that they become familiar with the curricular and instructional components of the unit. During the workshops teachers also discussed adaptations and modifications of the unit with their students from diverse languages and cultures (Lester et al.).

In another study, Pruneau and colleagues (2006) worked with teachers participating in a climate change education course to voluntarily demonstrate new environmental behaviors. The professional development approach in this case was conceived as collaborative action research. Two major types of activities were included. First, knowledge construction that helped students understand climate change such as its nature, signs, causes, and possible local consequences. Second, experiential and affective activities such as science experiments, a moment of solitude in nature, role playing, values activities, field trips, and experimentation with behaviors to reduce participants' impact on the climate. Throughout the course, particular emphasis on sharing among peers was placed to create a sense of community.

In what appears to be a very comprehensive approach to teacher learning, staff in the National Center for Atmospheric Research described lessons learned from eight years of providing in-person and online professional development for middle and high school teachers on climate change education (Johnson et al., 2011). Specifically, they emphasized several points consistent with literature on successful teacher professional development (City, Elmore, Fairman, & Teitel, 2009). For example, just like other studies they argue that during professional development, teachers need hands-on experiences engaging with relevant curricular resources in order to build confidence in using the materials in their own classrooms. They also emphasize the importance of community building among teachers, especially for the online workshops involving virtual communities of learners. In asking teachers about the kinds of resources and approaches that would best support their own teaching of climate change, participants cited the value of authentic climate data in user-friendly formats, making the topic personally-relevant for students (e.g., integrating local perspectives), and empowering students to believe they can make a difference. Like Matkins and Bell (2007), Johnson and colleagues also recommended emphasizing the nature of science and ongoing progress in climate change science, so that teachers feel comfortable teaching a topic characterized by "constant breakthroughs in scientific knowledge" (p. 510).

Integrating technology in the teaching and learning of climate change

A final aspect of teacher preparedness to address climate change in the classroom relates to their ability to integrate technology into their teaching. As computer technology has gained prominence in many aspects of science education, including climate change education (Lee & Krajcik, 2012; Svihla & Linn, 2012), technological literacy has become increasingly important for teachers and students examining climate change in the science classroom. Engagement with activities that feature technological resources such as visualization tools, interactive games, modeling, simulations, digital probes and virtual experimentation among others, can promote student learning as well as interest in science and technology (Swarat, Ortony, & Revell, 2012). Svihla and Linn (2012), for example, used visualizations representing the earth and atmosphere in the context of a project called Global Climate Change within the Web-based Inquiry Science Environment (WISE) (Slotta & Linn, 2009). Findings indicated that interactive visualizations provided rich sources of learning opportunities, particularly when embedded in inquiry sequences (Svihla, 2011; Svihla & Linn, 2012). Similarly Ryoo and Linn (2012) investigated how dynamic visualizations, compared to static illustrations, can support middle schools students' understanding of energy in photosynthesis. They noted significant advantages of dynamic visualizations, including students' ability to articulate the process of energy transformation more successfully and integrate their understanding of energy in photosynthesis. These findings suggest that dynamic visualizations can more effectively improve students' understanding of abstract concepts.

The power of visualizations and other digital technologies to improve student understanding, however, depends on the teacher's approach (Gerard, Liu, Corliss, Varma, Spitulnik, & Linn, 2012). Although students are engaged when using digital technology such as visualizations, they do not always link evidence from the visualization to scientific ideas (Gerard et al.). Teachers must provide guidance that helps students make predictions about the science concepts illustrated by technology, integrate ideas to explain scientific processes, and gather evidence to formulate scientific explanations and construct arguments (Gerard et al.). Yet, teachers often face substantial challenges when trying to design lessons and guide student learning through the use of computer modeling, simulation, visualization and other digital technologies (Gerard et al.).

Effective use of digital tools in the teaching and learning of climate change is based on teachers' ability to integrate technology with specific content and pedagogical strategies. These interactions among technology, content and pedagogy form the core of what has been called Technological Pedagogical Content Knowledge (TPACK) – a distinct type of flexible knowledge required for effective use of digital technologies in classroom teaching (Mishra & Koehler, 2006; Niess, 2005). Combining technology with content and pedagogy requires that teachers develop an understanding of what content to teach with technology, what technology to use (e.g., technology designed for science instruction, technology for doing science, etc.), and how to teach with particular technology (McCrory, 2008). Integration and modeling of digital technologies within preservice teacher preparation and professional development programs is, therefore, key to the development of TPACK. In fact, Gerard et al. (2012) demonstrated that more intensive professional development results in more effective teacher implementation of digital technology such as visualizations and greater student learning gains.

MADE-CLEAR APPROACH TO PRESENTING CLIMATE CHANGE IN PROFESSIONAL DEVELOPMENT FOR PRACTICING TEACHERS

Based on our comprehensive review of the literature and our own efforts to include climate change in science methods courses we have identified three key strategies for moving forward in effectively preparing science teachers to teach climate change education. These include: (a) alignment with local and national standards, including identification of resources and technologies that support those standards; (b) learning progressions as a tool to understand and assess student learning; and (c) research-based professional development.

Standards, Resources and Technologies

As science education programs change to incorporate current issues in climate science, a useful step is to identify the presence of climate change-related concepts in local curriculum standards. This is especially crucial as states update curricula in response to the NGSS and in individual state environmental literacy plans (NAAEE, 2013). After identifying climate-related concepts, science educators and curriculum planners can identify or develop curricular resources and technologies to meet these goals. Although no comprehensive climate change curricula exist to date, there is an abundance of high-quality materials, resources and technologies that can be used to compare and contrast multiple perspectives, encourage investigations, and analyze data underlying climate change issues. Part of our work in MADE CLEAR has been to identify and vet existing curricular resources and technologies from sources such as the Climate Literacy and Energy Awareness Network (cleannet.org) and Climate Adaptation, Mitigation, and E-Learning (camelclimatechange.org) that can be used or modified to address formal science curriculum standards (e.g., NGSS) and informal science education program goals. Below we provide two examples of curricular and technology resources that can be used to address core climate change concepts.

Example 1

A key climate change concept within the NGSS focuses on the use of models to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate (see Table 1, Performance Standard HS-ESS2-4). In order to help students gain coherent ideas about energy transfer and transformation as it relates to global climate change, Slotta & Linn (2009) designed a unit within WISE which incorporated NetLogo visualizations representing the earth and atmosphere (see Figure 1). Students explore albedo, carbon dioxide emissions, population, and pollution as factors leading to climate change (Varma, 2008). To improve comprehensibility of the visualizations, Svihla and Linn (2012) introduced annotated screenshots of the visualization, a pivotal case on the role of energy transformations in global climate processes, prompts that helped students distinguish ideas about the atmosphere as a blanket and a shield, and structured experimentation that allowed more systematic manipulation of variables within the simulation. These activities were situated within the knowledge integration framework, which emphasized science learning that requires students to integrate ideas from multiple sources and determine the most fruitful, generative, and coherent perspective (Linn & Hsi, 2000). Evidence indicated that students had good understanding of the visualization and gained insight into climate change variables such as the atmosphere and albedo by interacting with visualizations. They could also make decisions about everyday activities related to energy use and carbon production.

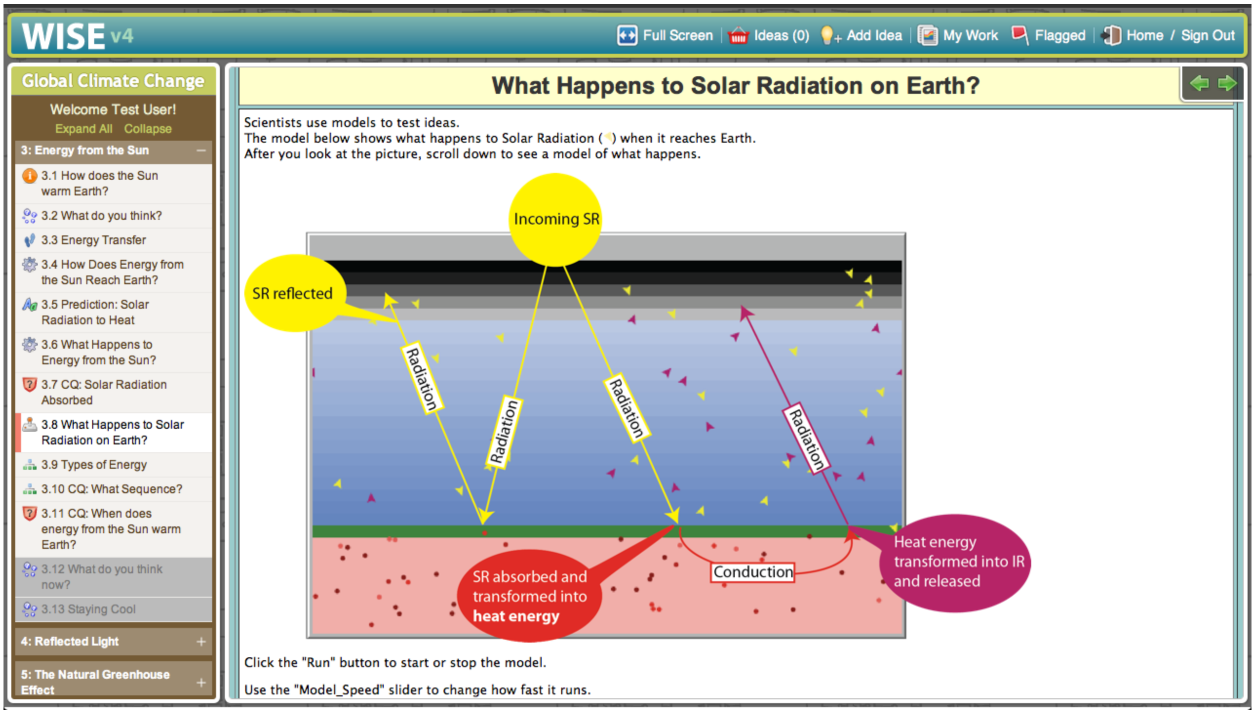

Figure 1. Dynamic visualizations within WISE (from WISE, 2012)

Example 2

A second key climate change concept within the NGSS focuses on analysis of geoscience data such as precipitation and temperature and their associated impacts on earth systems (e.g., sea level; see Table 1, Performance Standard HS-ESS3-5). The Center for Operational Oceanographic Products and Services (Co-OPS) has gathered oceanographic data along the US coasts for over 200 years. Students can access and analyze those data online looking for areas where sea levels are increasing in the US and making inferences as to what is causing sea level rise. Further, they can access data specific to each state in order to investigate historical trends in more depth (see Figure 2). Similarly, scientists from Delaware Coastal Programs used a simple model to develop maps that demonstrate the possible impacts of inundation based on various sea level rise scenarios for Delaware's waterways and the land that surrounds them (watersheds; see Figure 3). Local resources are key to helping students gain a scientific understanding of the observations of the differing impacts of climate change in their local areas' environment. When learners gain new understandings about how climate change impacts their local environment, they may also be motivated to take actions to make a difference in preventing or addressing these impacts (NCADAC, 2013).

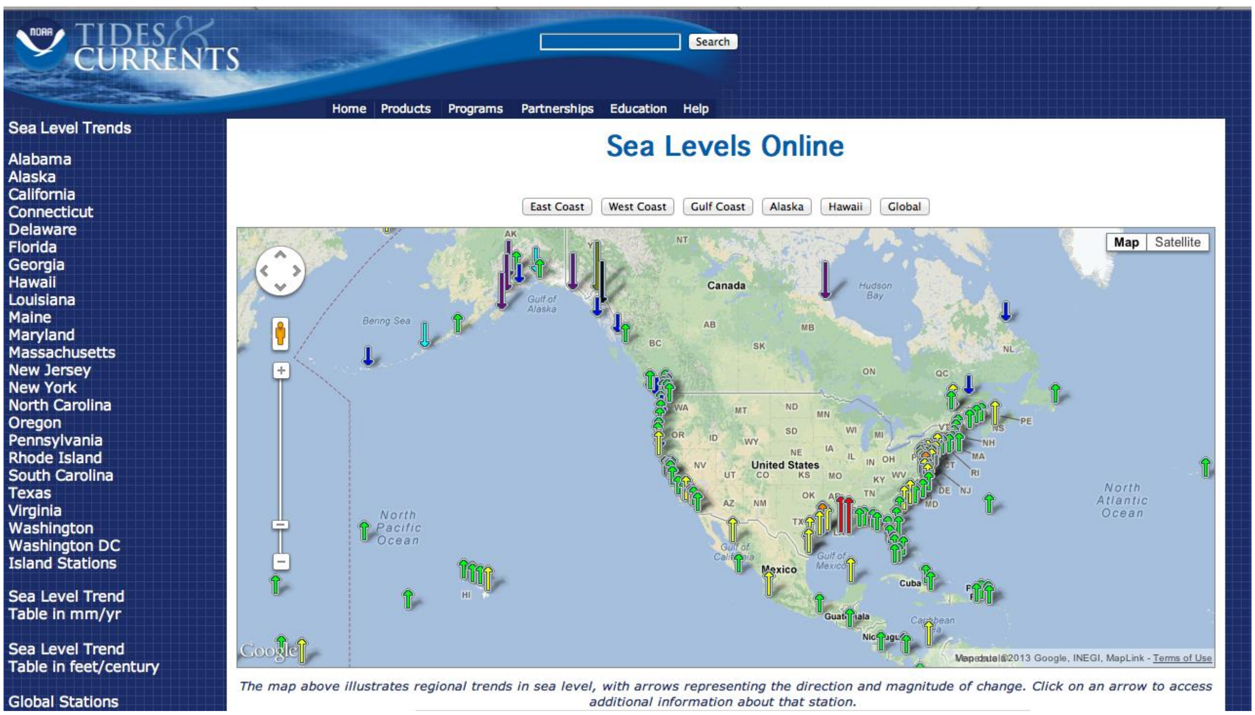

Figure 2. Historical data on sea level rise (from NOAA, 2013)

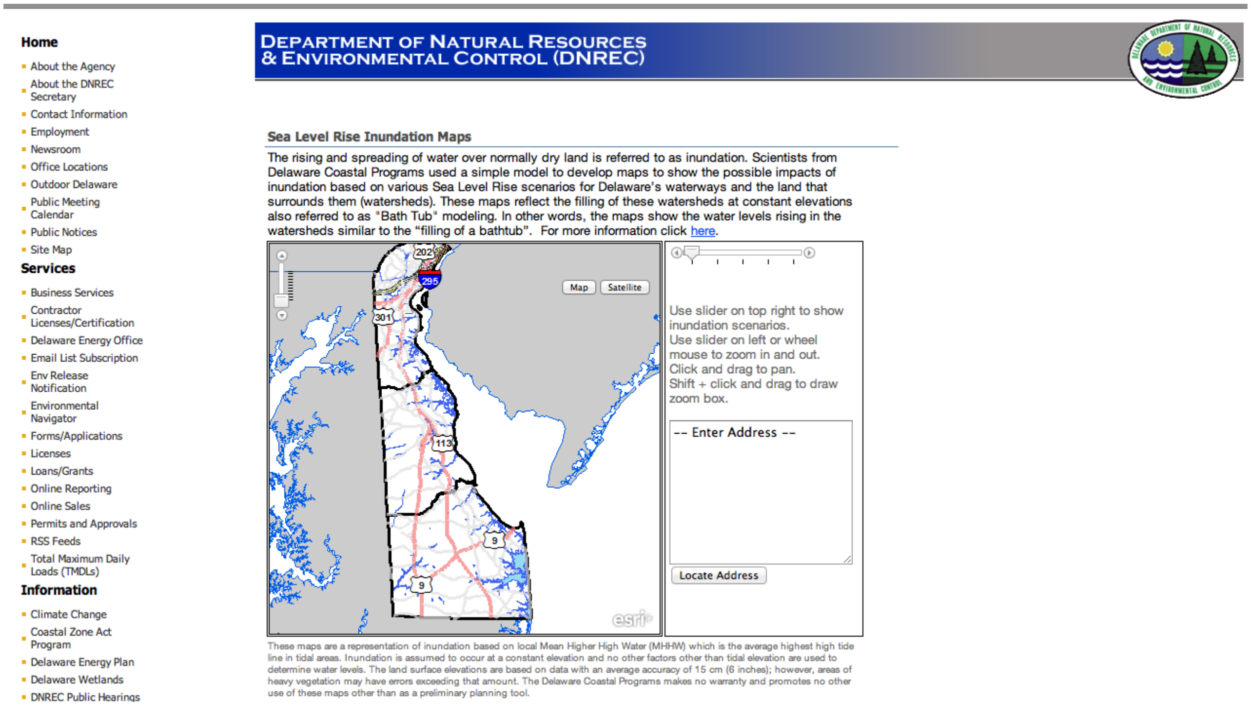

Figure 3. Interactive maps on sea level rise in Delaware (DNREC, n.d.)

Learning Progressions

Learning progressions (LPs) provide a rich framework for understanding when and how students can learn about climate change at various levels (Mohan, Chen, & Anderson, 2009). Smith, Wiser, Anderson, Krajcik, and Coppola (2004) describe LPs pedagogy as where "big ideas can be understood in progressively more sophisticated ways students gain in cognitive abilities and experiences with phenomena and representations" (p.5). The LP starts with a Lower Anchor (representing the understanding of a typical fourth grade schools student) and ends with an Upper Anchor (representing the standards that society would want a high school student to meet upon graduation). With these ideas in mind, we are developing and empirically testing three hypothetical LPs derived from our analysis of the NGSS: sea level rise, extreme weather, and urban heat island effect (see Table 3 for one component). We selected these three observable phenomena in the environment as particularly relevant for the diverse geographical regions within our two states, Maryland and Delaware, in which MADE CLEAR's work is focused.

	Level 1 (Lower Anchor)	**Level 2**	**Level 3**	**Level 4** (Upper Anchor)
Potential SLR LP indicator about impacts of sea-level rise "I" stands for impacts	I1: Students identify that an impact of sea level rise is that some land in coastal areas and islands will be underwater though they are not able to elaborate on specific consequences of sea level rise.	I2: Students understand that sea level is projected to rise in the future and are able to identify a limited number of specific consequences, though they do not understand that sea level change will have local effects including those related to storm surge.	I3: Students understand that local impacts of sea level changes can differ, but cannot explain primary factors that can cause this difference. Students are able to elaborate on specific consequences of sea level rise such as loss of habitat, in-land flooding during storms, property loss, and erosion.	I4: Students understand that local sea level changes can differ from global trends based on regional variations in factors such as geographic uplift or subsidence and ocean currents. Students are able to elaborate on specific consequences of local sea level rise. Students recognize that sea level rise projections are based on available data and may be lower or higher than predicted.

TABLE 3. DRAFT HYPOTHESIZED LEARNING PROGRESSION FOR SEA LEVEL RISE IMPACTS

To begin the LPs development process, we defined four Levels of Achievement. We started with the most sophisticated understanding (Level 4) of the targeted scientific construct as represented in the high school grade level component of the NGSS. We then hypothesized, based on prior literature concerning student conceptions of natural phenomena, the knowledge students would be expected to bring to school (Level 1). Next, we constructed intermediate Levels of Achievement (Levels 2 and 3), using information from prior literature and crosschecking for alignment with the NGSS. In testing these LPs, we seek new insights into the ways in which a regional observations approach to climate change education may influence student learning. We also seek to assist teachers in understanding how LPs can help them to gain insight into student thinking, guide their assessments, and inform their adjustments to their teaching according to students' needs.

Professional Development

Finally, to support educators in integrating climate change into their existing practices, high quality professional development experiences are needed for informal educators, preservice teachers, and practicing science teachers. These experiences can provide valuable opportunities to become familiar with salient issues in the study of climate change and participate in communities of practice committed to improving climate literacy. In our own professional development efforts with middle and high school science teachers, we are cognizant of the challenges teachers frequently face in translating professional development experiences to classroom contexts. As City et al. (2009) described, lack of a common instructional vision applied to daily instructional practice in schools, the siloed culture of schooling, and lack of process for translating new knowledge to teaching practice, often present obstacles for realizing professional development goals. To address these challenges, we seek to incorporate processes suggested by City et al. such as lesson examination; science content study in consultation with climate scientists; lesson refinement, delivery, and observation; individual reflections; and group debriefing to generalize to practice (see Table 4).

PD Process	**Description**
Lesson Examination	*Teachers* select a lesson topic in climate change that aligns with the NGSS and local science standards, examine instructional materials and technologies, review prior evidence from the literature of students' anticipated conceptions of the topic, and difficulties with the core science concept, and collaboratively consider strategies to teach the topic.
Science Content Study	*Teachers* consult with science and pedagogy experts to improve their science content knowledge and pedagogical knowledge informed by learning progressions and sociocultural research for a sensitive topic. They then develop statements that clearly identify the core science concepts their students need to understand to learn the topic and how they align with science standards.
Lesson Refinement	*Teachers* collaboratively design a lesson (or series of lessons) by integrating instructional strategies that support student learning of core science concept (e.g., craft questions to move students' thinking to higher levels of cognitive demand, utilize technologies that help students visualize scientific concepts, emphasize argumentation based on evidence, diversify lesson for all learners that includes

	consideration of salient sociocultural factors).
Lesson Delivery and Observation	*One teacher* volunteers to teach the lesson to students according to the collaboratively developed plan. *Remaining teachers* observe the lesson implementation (live or recorded), focusing on the students (rather than on the volunteer teacher) and examining data evidence of students' learning.
Individual Reflection	*Individual teachers* reflect on the lesson observation with questions such as "What happened?" "How did it play out?" and "Why did learning occur in the observed way?"
Debrief and Generalization to Practice	*Teachers* identify (a) connections between student learning and successful aspects of the lesson design, (b) connections between the instructional strategies employed and student learning, and (c) generalizations about how effective strategies can be applied to future instructional practice.

TABLE 4. PROFESSIONAL DEVELOPMENT PROCESS SUGGESTED BY CITY ET AL. (2009) APPLIED TO A TEACHER WORKSHOP ON CLIMATE CHANGE EDUCATION[1]

[1]Taken from McGinnis, Breslyn, McDonald, & Hestness, (2013)

CONCLUSION

We believe that the confluence of changes in our global climate and local communities, the science education landscape in the era of NGSS, and public awareness of climate change have set the stage for a new chapter in climate change education. With increased public awareness, and a place in the NGSS serving as catalysts for climate change education, teacher preparation and professional development will be an essential part of an effective and sustainable approach to climate change education. Geoscience educators can be a guiding voice in professional development that enables science educators to enrich and extend their knowledge of climate science and current issues on global and local scales, build confidence in climate change content and pedagogy, and gain access to high quality curricular materials. While the story continues to unfold, we believe that in moving climate literacy forward, the geoscience education community is well positioned to assume a leading role.

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