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Science Teacher Professional Development in Climate Change Education Informed by the Next Generation Science Standards

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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 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. Literature in this domain underscores the complex nature of climate change, curriculum and instruction challenges related to teaching the topic, recommended practices for teacher education and professional development, and the emerging role of technology integration for addressing climate change in the science classroom. Finally, we present one approach to teacher professional development around climate change education, emphasizing: (1) the need for quality standards-aligned curricular resources to support climate change instruction, especially those that integrate technology; (2) the potential of regional observations-focused learning progressions for making climate change personally relevant to learners; and (3) the value of research-based professional development and teacher education for advancing climate change education. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-049.1]

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 (Intergovernmental Panel on Climate Change, 2013), and many Americans are beginning to directly observe climate-related changes in their own communities (U.S. Global Change Research Program, 2014). In the realm of science education, the salience of climate change became particularly evident with the recent release of the Next Generation Science Standards (NGSS) (NGSS Lead States, 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 learners 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 et al., 2009; Jin and Anderson, 2012). This imbalance between climate change awareness and scientific literacy around climate change underscores the need for science educators who are prepared to teach about the science of climate change and its impacts.

The 2013 release of the final version of the NGSS, "a new set of voluntary, rigorous, and internationally benchmarked standards for K–12 science education" (Achieve Inc., 2013), 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 I provides examples of relevant NGSS performance standards from the domain of Earth and Space Sciences, the only content area within the NGSS in which climate change is explicitly mentioned.[3] While the topic does not directly appear in the physical sciences 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]).

Despite positive advances toward making climate change a meaningful part of K–12 science instruction, major challenges remain. First, climate change is a highly complex phenomenon cutting across scientific disciplines, including the social sciences. As a scientific issue frequently associated with the political realm, climate change may be viewed as a sensitive topic to discuss in the science classroom. As a socioscientific issue, addressing climate change in the classroom may also involve addressing its potentially challenging moral and ethical dimensions (Zeidler and Keefer, 2003; Sadler and Zeidler, 2005; Sadler, 2011). At

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[3] For a comprehensive listing of performance standards related to the topic of climate change, see http://www.climateedresearch.org/publications/2013/Climate-Change-NGSS.pdf.

TABLE I: Sample NGSS high school performance standards relevant to climate change education.

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 freshwater (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.

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

times, science teachers have viewed these aspects as problematic or outside the realm of their roles as science teachers (McGinnis, 2003). Second, although climate change as a topic is highly interdisciplinary, much of its explicit focus in the NGSS is placed within the discipline of Earth and Space Sciences (see Table I). This placement may become problematic because, presently, many U.S. students do not take Earth Science in high school (McNeal, 2010) and therefore may not have opportunities to engage in science learning activities specifically focused on climate change. While this is problematic, the positioning of climate change in the Earth and Space Sciences may also create the potential for a renewed emphasis on the geosciences in science education.

These challenges underscore the complexities of climate change education. They raise critical questions around implications for curriculum and instruction, teacher education, and professional development toward the goal of supporting learners in developing a holistic and scientifically informed understanding of the issue. To provide insights for moving ahead, we begin by presenting a review of science education literature, examining 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 this review by describing one example of a climate change education initiative, MADE CLEAR, which supports science teachers in addressing these challenges by engaging them in professional development activities emphasizing the use of curricular resources, technologies, and regionally relevant approaches to foster learner understanding of climate change.

REVIEW OF THE LITERATURE

Learning to Teach Complex Climate Science Content

In preparing learners 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 Earth's energy balance (Ekborg and Areskoug,

TABLE II: Sample alternative conceptions related to climate change.

Alternative Conceptions	Study
Global warming is caused by a hole in the ozone	Dove (1996); Ekborg and Areskoug (2006); Hestness et al. (2011); Lambert et al. (2012); Matkins and Bell (2007); Michail et al. (2007); Papadimitriou (2004); Wise (2010)
Global warming causes skin cancer	Dove (1996); Ekborg and Areskoug (2006); Groves and Pugh (1999); Michail et al. (2007)
The greenhouse effect is caused by a lid or blanket that traps heat	Dove (1996); Ekborg and Areskoug (2006); Lambert et al. (2012); Papadimitriou (2004)
The carbon cycle acts like a filter that cleans the air	Lambert et al. (2012)
Confusion about weather vs. climate	Lambert et al. (2012); Papadimitriou (2004)
Greenhouse gases are "trapped" in the atmosphere	Lambert et al. (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	Matkins and Bell (2007); Wise (2010)
Increasing the greenhouse effect would increase earthquake frequency	Groves and Pugh (1999)
Using unleaded gasoline can reduce the greenhouse effect	Groves and Pugh (1999)
Nuclear power or weapons contribute to the greenhouse effect as much as coal power	Groves and Pugh (1999); Papadimitriou (2004)
Environmental pollution generally causes global warming	Papadimitriou (2004)
Acid rain causes global warming	Groves and Pugh (1999); Papadimitriou (2004)
The greenhouse effect is unnatural	Matkins and Bell (2007); Michail et al. (2007)

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 et al., 2012).

Teacher Content Backgrounds and Understandings

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 they 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 et al., 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 and 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 (National Research Council, 2012).

Alternative Conceptions

Among teachers, several alternative conceptions regarding climate change science have repeatedly emerged in the literature (see Table II). 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 alternative conceptions around the carbon cycle, how greenhouse gases enhance the greenhouse effect, and the distinction between climate and weather. The recurrence of these issues raises questions about whether teachers run the risk of communicating scientifically inaccurate climate change information to their students.

Aside from the challenges around disciplinary core ideas related to climate change, 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 sets accessible so that teachers and learners can utilize them to draw evidence-based conclusions. They have also emphasized the need for increasing teachers' content knowledge and understandings of the nature of science (National Research Council, 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 and 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. In attempt 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). 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 learners 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 learners' 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 that 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" (National Research Council, 2012, p. 38), or they may present claims in the classroom that are at odds with scientifically agreed upon understandings.

Policy Considerations

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. Policy conversations regarding the teaching of climate change have proliferated with the release of the NGSS. In this context, 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, 2011).

Climate Change as a Potentially Sensitive Topic

In navigating the sensitive nature of the climate change topic, teachers may 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 (National Research Council, 2012). Johnson et al. (2008) 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 learners and teachers gain a better understanding of the practice of climate science. Science educators and researchers, as well as the Core Science and Engineering Practices dimension of the NGSS, have emphasized that teachers must model the practices of science by engaging learners in taking measurements, making observations, and making connections with the ongoing research in which climate scientists are engaged (National Research Council, 2012). They also argue that it is beneficial to learner understanding of climate change when teachers connect local changes to changes in the larger global system. Finally, 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., 2008). 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 et al., 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 learners 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, moral, and ethical overlays provides a more holistic representation of climate change as a real-world issue about which learners must be prepared to make decisions as citizens.

Curricular Inclusion

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 (National Research Council, 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, 2010). 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 (National Research Council, 2012). Such problems associated with curricular compartmentalization have prompted some to argue for a reimagining 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 Preservice 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. Several teacher educators have described their experiences working with preservice teachers on climate change education (Ekborg and Areskoug, 2006; Matkins and Bell, 2007; Hestness et al., 2011; McGinnis et al., 2011; Lambert et al., 2012). These studies and others suggest that interventions in preservice teachers' science content and science methods courses can improve teachers' preparedness to address climate change in the classroom.

Promoting Content Understanding

Recognizing that teachers may have similar alternative conceptions 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 commonly held alternative conceptions. By the end of the courses, they noted fewer alternative conceptions than had been reported in previous studies (e.g., Boyes and Stannisstreet, 1992), suggesting that the courses' design—which attended specifically to common areas of confusion in climate change science—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 (National Research Council, 2012). Also with regard to course design, Ekborg and Areskoug highlighted the importance of making connections between courses within teacher preparation programs, so that preservice 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 (Matkins and Bell, 2007; Hestness et al., 2011; Lambert et al., 2012). Lambert et al. (2012) infused a climate change curriculum into an elementary science methods course. They measured changes in preservice 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 noted that some students demonstrated problematic alternative conceptions even after the intervention and called for the continued development of tools that could help to identify teachers' alternative conceptions related to climate change.

Promoting Preparedness to Teach About Climate Change

In addition to gains in content knowledge, other studies examining the exploration of climate change in preservice teacher education have reported evidence of 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 and Bell, 2007). Like Lambert et al. (2012), Matkins and Bell 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 postinstruction views of the nature of science and climate change. They argued for the value of "explicit, contextualized nature of science instruction" (p. 139) to support preservice 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 related to 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 own work integrating climate change into an elementary science methods course, we observed that a climate change education intervention had the potential to significantly increase preservice teachers' sense of preparedness to teach about climate change (Hestness et al., 2011; McGinnis et al., 2011). In particular, we saw value in making connections between course activities and preservice teachers' professional development school environments, including a focus on data collection, analysis, and interpretation; and promoting active learning. However, we posited that teacher candidates needed longer-term study of relevant science content outside of science teaching methods courses. We also found that teacher candidates benefited from reflective activities, such as journaling and discussion, as they were developing 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. While the body of research on teacher professional development specific to climate change education is limited at present, findings from existing studies coalesce around several key themes. These include the importance of designing professional development that addresses the unique affordances and challenges of the climate change topic, addressing practicing teachers' needs for increased climate change science content knowledge and relevant pedagogical strategies, and the value of communities of practice as science educators consider the inclusion of climate change in their teaching (Hestness et al., 2014).

Strategies for Introducing Climate Change to Learners

Practicing science teachers may be likely to regard climate change as a motivating and relevant topic for their learners, particularly given its prominence in the media (Gayford, 2002; Johnson et al., 2008). In describing lessons learned from 8 y of providing in-person and online professional development for middle and high school teachers on climate change education, Johnson et al. noted that this motivation can be leveraged through instruction by making the topic of climate change personally relevant (e.g., by integrating local perspectives) and by examining ways to empower learners to believe they can make a difference. The presence of climate change in the media may likewise present challenges that science educators must be prepared to address—particularly the perception of climate change as a controversial topic. In their study of museum educators' experiences teaching a climate change education program, Allen and Crowley (2014) found that educators may avoid key aspects of climate change science (e.g., causes of accelerated climate change) if they perceive them to be potentially controversial. This suggests that professional development opportunities should prepare teachers to help navigate such tensions without avoiding key science content. Another challenge—and affordance—for teachers of science is that climate change is a prime example of "science-in-the-making" (Latour, 1987 in Kolstø, 2001, p. 294). While uncertainties (e.g., variations in projections around future warming) may be inappropriately used to argue that there are high levels of scientific uncertainty about whether climate change is happening and will continue, the growing body of knowledge around climate change, and ongoing refinement of scientific understandings, may present an opportunity for teachers to emphasize the dynamic nature of science. Toward this end, professional development experiences should support teachers' abilities to teach a topic characterized by "constant breakthroughs in scientific knowledge" (Johnson et al., 2008, p. 510).

Modeling and Practicing Approaches to Teaching

With regard to climate change education pedagogy, researchers have noted the value of ongoing professional development opportunities that provide science teachers with a venue to engage with actual learning activities that can be used with learners (Lester et al., 2006; Johnson et al., 2008; Allen and Crowley, 2014). For example, Lester et al. (2006) found that teachers benefited from a professional development workshop series in which they could practice climate change education lessons and discuss with colleagues potential adaptations for their specific teaching contexts. Likewise, Allen and Crowley noted that informal science educators were able to improve their climate change education practices through a guided process of teaching and iteratively redesigning their approaches. In addition, Pruneau et al. (2006) described how experiential and affective activities such as science experiments, a moment of solitude in nature, role playing, field trips, and experimentation with behaviors to reduce their own environmental impact helped teachers to evolve in their own thinking during a climate change education professional development experience. Such studies suggest that teachers benefit from hands-on experiences engaging with relevant curricular resources, which can help to build confidence in using the materials in their own teaching practice.

Fostering Communities of Practice

Finally, many of the studies of teacher professional development related to climate change education emphasize the importance of communities of practice. Teachers may often view fellow teachers as a highly reliable source of advice and ideas (Gayford, 2002). Therefore, teachers may especially benefit from professional development opportunities that promote community building and collaboration amongst teacher peers, including through discussion opportunities such as practitioner focus groups (Allen and Crowley, 2014) and in online spaces involving virtual communities of practice (Johnson et al., 2008). Such approaches may promote sharing of ideas, encouragement, and mutual support through a process of change (Pruneau et al., 2006).

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 and Krajcik, 2012; Svihla and Linn, 2012), technological literacy has become increasingly important for teachers and learners 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 et al., 2012). Svihla and Linn (2012), for example, used visualizations representing Earth and the atmosphere in the context of a project called Global Climate Change within the Web-based Inquiry Science Environment (WISE) (Slotta and Linn, 2009). Findings indicated that interactive visualizations provided rich sources of learning opportunities, particularly when embedded in inquiry sequences (Svihla, 2011; Svihla and Linn, 2012). Similarly, Ryoo and Linn (2012) investigated how dynamic visualizations, compared to static illustrations, can support middle school learners' understanding of energy in photosynthesis. They noted significant advantages of dynamic visualizations, including learners' 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 learners' understanding of abstract concepts.

Scaffolding Learner Understandings

The power of visualizations and other digital technologies to improve learner understanding, however, depends on the teacher's approach (Gerard et al., 2012). Although learners are engaged when using digital technology such as visualizations, they do not always link evidence from the visualization to scientific ideas (Gerard et al., 2012). Teachers must provide guidance that helps learners 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., 2012). 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., 2012).

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 (Niess, 2005; Mishra and Koehler, 2006). 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 are, therefore, keys 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.

Summary

Research on climate change education underscores unique challenges and possibilities for teacher professional development. Because climate change is a complex topic of ongoing scientific investigation, these studies point to the importance of providing teachers with opportunities to gain new understandings of science content through professional development that can increase their confidence in teaching about climate change. While the salience of climate change in the media and sociopolitical sphere may present additional complexities in the classroom, it may also contribute to learners' interest in the topic. Professional development around climate change should seek to help teachers consider ways to leverage students' interests for learning, and design instruction that helps learners to recognize the relevance of climate change for their own lives and for the world. Toward this end, teachers may benefit from working collaboratively in professional development experiences through explorations of relevant data, curricular resources, lesson ideas, and technology tools they can use to address standards-based curriculum goals in engaging and relevant ways for learners. These collaborations might include members of both the climate science and science education communities. By establishing communities of practice around climate change education, teachers may be able to share ideas and resources on an ongoing basis and learn from one another's successes and challenges addressing climate change in the classroom. Finally, by supporting teachers in developing TPACK, professional development experiences can support teachers in using technology to engage students in the dynamic field of climate change science (e.g., through real-time visualizations) and support learning.

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

Having reviewed the literature, we turn now to a description of one professional development initiative that responds to research-based recommendations around climate change education while also piloting several new approaches. The initiative, Maryland and Delaware Climate Change Education, Assessment and Research (MADE CLEAR), focuses on the implementation of a comprehensive climate change education plan for this region, involving collaboration among formal and informal science educators, climate scientists, public mass communication outlets, and science education researchers. MADE CLEAR addresses climate change education through the lens of regional observations (U.S. Global Change Research Program, 2014), with the goal of supporting learners in constructing explanations about climate change relevant to their own lives and communities. To support teachers in this work, MADE CLEAR focuses specifically on (1) identifying resources and technologies to support teaching and learning around local and national (NGSS) standards; (2) using regionally relevant learning progressions as tools to understand and assess student learning; and (3) providing educators with research-based professional development opportunities.

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 curriculum standards. We analyzed the NGSS for this purpose, noting the disciplinary core ideas and related performance standards that are explicitly or proximally related to climate change (www.climateedresearch.org/publications/2013/Climate-Change-NGSS.pdf). There is an abundance of high-quality materials, resources, and technologies that can be used to address these standards. 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 support teaching and learning about climate change in both formal and informal science learning settings. Educators can search for vetted resources by topic and grade level through the MADE CLEAR project Web site (madeclear.thinkport.org). Next, we provide an example of how technology resources can be used to address core climate change concepts.

Example

A key climate change concept within the NGSS focuses on analysis of geoscience data such as precipitation and

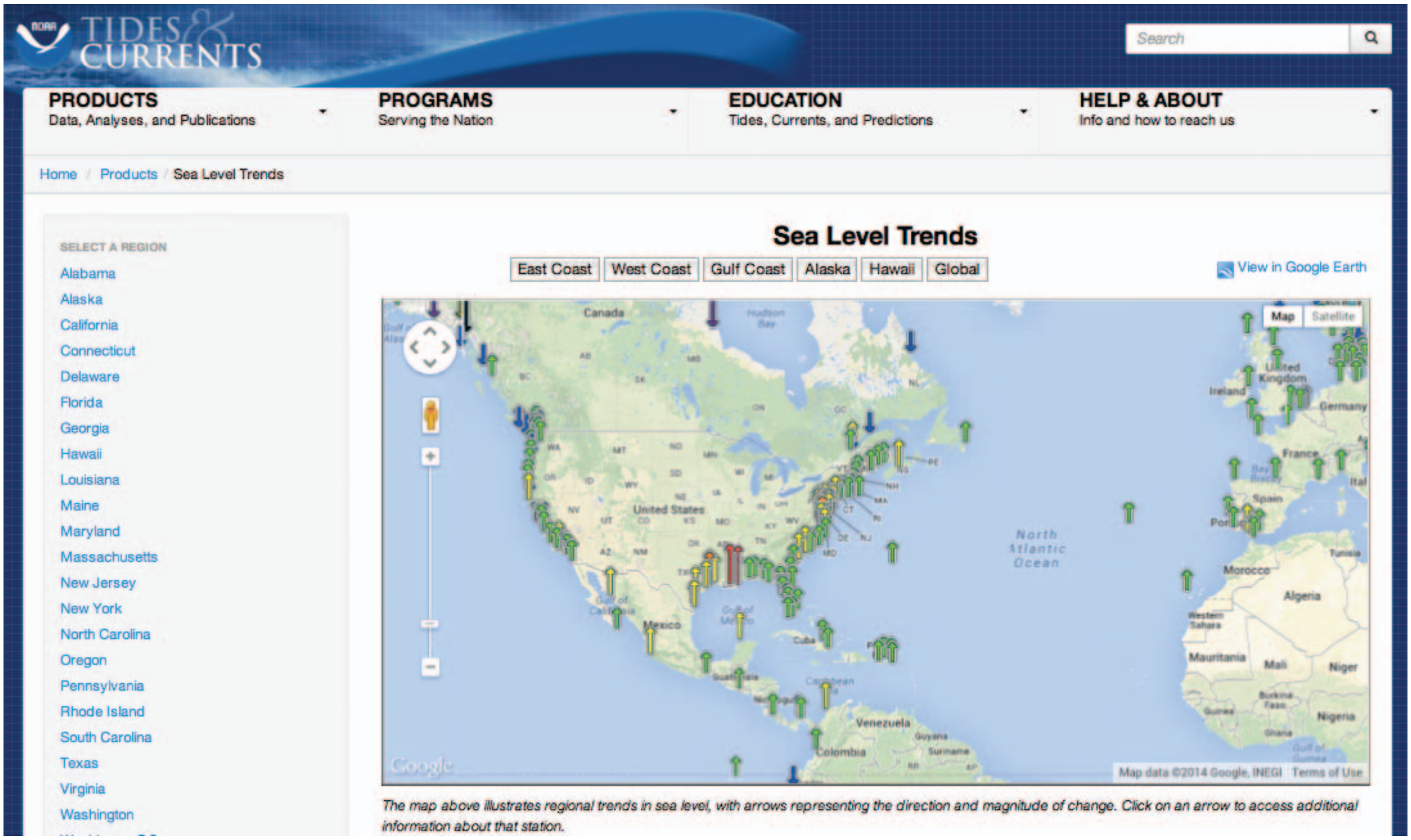

FIGURE 1: Historical data on sea-level rise (from NOAA, 2013).

temperature and their associated impacts on Earth systems (e.g., sea level; see Table I, Performance Standard HS-ESS3-5). The Center for Operational Oceanographic Products and Services (Co-OPS) has gathered oceanographic data along the U.S. coasts for over 200 y. Learners can access and analyze those data online, looking for areas where sea levels are increasing in the United States 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 Fig. 1). 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 Fig. 2). Local resources are key to helping learners 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.

Learning Progressions Focused on Regional Observations of Climate Change

Learning progressions (LPs) provide a rich framework for understanding when and how learners can learn about climate change at various levels (Mohan et al., 2009). In their comprehensive review of the development and reporting of learning progressions, Duschl et al. (2011) stated that learning progressions in science education "are seen as *de rigueur* strategies for formulating and developing environments of learning that align curriculum, instruction, and assessment" (p. 124). Smith et al. (2004) described pedagogies informed by learning progressions as providing opportunities for learners to understand "big ideas…in progressively more sophisticated ways" (p. 5) and to "gain 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 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: extreme weather, extreme heat, and sea-level rise (for the sea-level rise example, see www.climateedresearch.org/publications/2012/SLR-LP.pdf). We selected these three observable phenomena as particularly relevant for the diverse geographical regions within the two states in which MADE CLEAR's work is focused. 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 adjustments to their teaching.

Professional Development

Finally, to support educators in integrating climate change into their existing practices, high-quality professional development experiences are required. These experiences

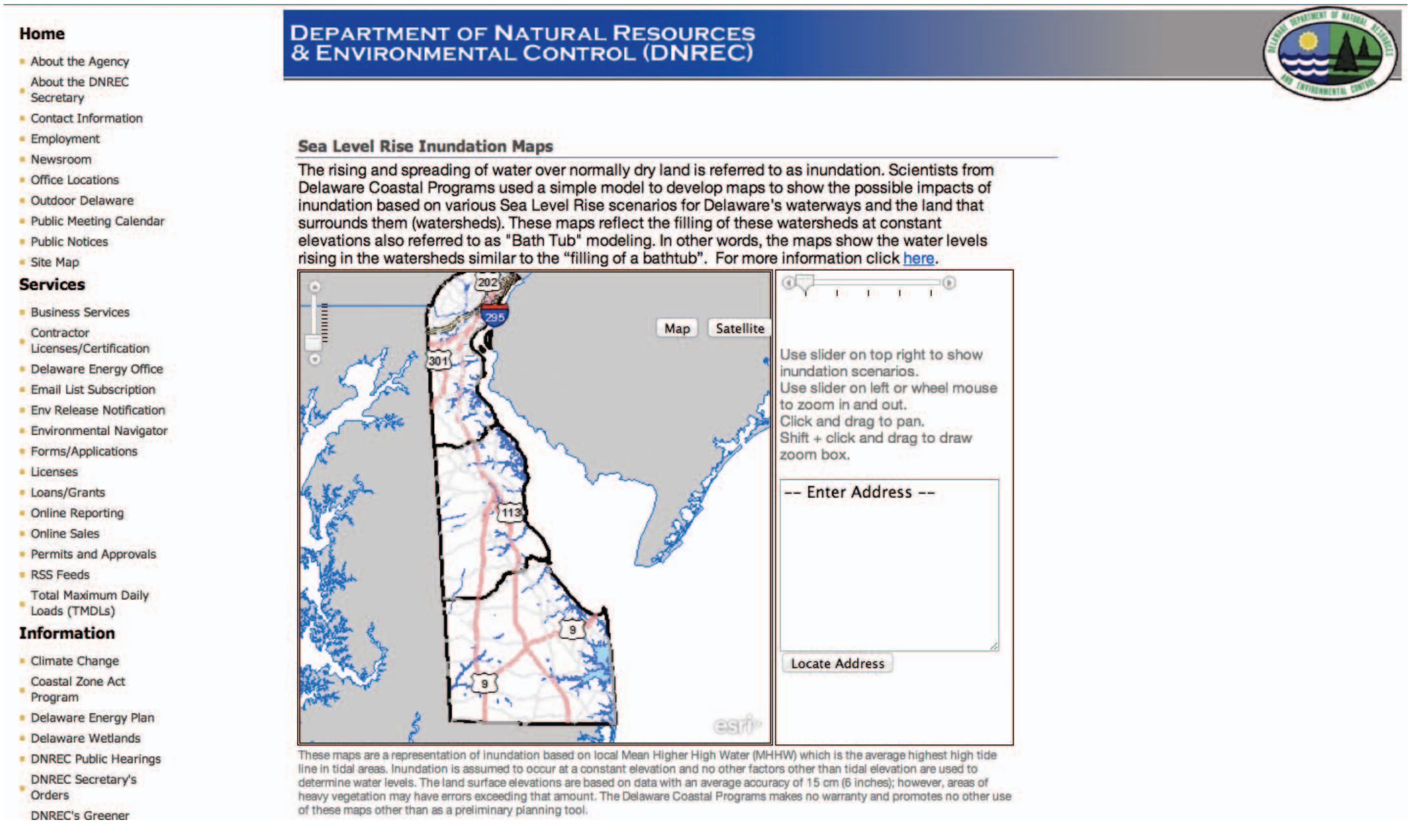

FIGURE 2: Interactive maps on sea-level rise in Delaware (DNREC, 2014).

TABLE III: Professional development (PD) process suggested by City et al. (2009) applied to a teacher workshop on climate change education.[1]

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 learners' 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 learners 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 learners' thinking to higher levels of cognitive demand, utilize technologies that help learners visualize scientific concepts, emphasize argumentation based on evidence, diversify lesson for all learners, which includes consideration of salient sociocultural factors).
Lesson Delivery and Observation	One teacher volunteers to teach the lesson to learners according to the collaboratively developed plan. Remaining teachers observe the lesson implementation (live or recorded), focusing on the learners (rather than on the volunteer teacher) and examining data evidence of 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 (1) connections between student learning and successful aspects of the lesson design, (2) connections between the instructional strategies employed and student learning, and (3) generalizations about how effective strategies can be applied to future instructional practice.

[1]Taken from McGinnis et al. (2013).

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 MADE CLEAR professional development efforts with middle and high school science teachers, we are cognizant of the challenges teachers may face in translating professional development experiences to classroom contexts. As City et al. (2009) described, the 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, MADE CLEAR seeks to incorporate processes suggested by City et al. (2009), 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 III).

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 has 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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