JOURNAL OF GEOSCIENCE EDUCATION **62**, 538–549 (2014)

Undergraduate Climate Education: Motivations, Strategies, Successes, and Support

Karin B. Kirk,[1] Anne U. Gold,[2] Tamara Shapiro Ledley,[3] Susan Buhr Sullivan,[2] Cathryn A. Manduca,[1] David W. Mogk,[4] and Katryn Wiese[5]

ABSTRACT

Climate literacy is an essential component of a strategy to comprehend and confront the grand challenge of global climate change. However, scientific complexity, societal implications, and political associations make climate change a difficult but important topic to teach. In this paper we report on the results of a survey of undergraduate faculty members on their teaching practices with respect to climate science and the outcomes of a series of undergraduate faculty workshops focused on climate change topics and intended to support faculty members in teaching these topics. Survey results show that undergraduate faculty members place a high priority on teaching climate science because of its relevance to the students with respect to their community, lives, and potential careers. In addition, the survey indicates that climate concepts are taught in a spectrum of undergraduate classes, ranging from geoscience classes to those in the social sciences that address societal impacts and solutions to the problems created by climate change. Results from the survey and workshops indicate there are multiple successful strategies for teaching climate topics, including focusing on solutions, using local contexts, teaching with scientific data, embracing that controversy is an integral part of teaching about climate change, and employing effective communication strategies that can help address controversy and misconceptions. We suggest that undergraduate faculty members need ongoing support in their efforts to effectively teach climate change topics. The Climate Literacy and Energy Awareness Network and On the Cutting Edge projects strive to provide that support through workshops and Web portals that provide access to a variety of educational materials. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/13-054]

Key words: climate education, climate change, global warming, misconceptions, pedagogy, faculty development, preparing students, societal issues.

INTRODUCTION

Climate change is a pressing challenge for our society (NCA, 2014). The topic is scientifically complex (IPCC, 2013), is politically charged (Hamilton, 2011; McCright and Dunlap, 2011), and has profound implications for ecosystems and societies across all parts of the globe (IPCC, 2014). As with many societal issues, effective educational efforts need to reach across varied audiences, via multiple channels, and by many types of educators (Wegner, 2008). Despite numerous challenges, educators are reporting positive results from instructional efforts (Sullivan et al., in press).

Over the course of 6 y and seven workshops, the authors have engaged hundreds of faculty members from institutions across the U.S. and beyond. We have aggregated this information to create an overview of climate education in higher education. Thus, the purposes of this paper are twofold. First, we present a synthesis of self-reported data about climate teaching practices in the undergraduate setting. Second, we summarize the results of professional development efforts and describe themes and resources that are aimed at increasing the effectiveness of undergraduate climate education.

The professional development programs discussed herein are the Climate Literacy and Energy Awareness Network (CLEAN) and On the Cutting Edge. The CLEAN project identifies, aggregates, reviews, and disseminates peer-reviewed climate education resources and offered a series of professional development workshops. The On the Cutting Edge Professional Development Program for Geoscience Faculty supports undergraduate geoscience teaching via workshops, pedagogic materials, and a collaborative network of faculty members. Together, these projects have engaged more than 200 college faculty members who teach climate topics. By working with this network of climate educators, we have learned how and why faculty members teach climate, where their challenges lie, what methods have worked for them, and where their best successes have occurred. These results shed light on effective strategies and allow the educational community to move forward by leveraging proven successes, building off of current work, and engaging their peers in the educational and scientific communities.

METHODS

While the CLEAN and On the Cutting Edge projects are largely engaged in providing professional development to educators, we have learned much from our participants as well. We have gathered a variety of data about how, why,

Received 15 June 2013; revised 21 July 2014 and 22 August 2014; accepted 10 September 2014; published online 19 November 2014.

[1]Science Education Resource Center at Carleton College, One North College Street, Northfield, Minnesota 55057, USA
[2]CIRES, University of Colorado Boulder, 449 UCB, Boulder, Colorado 80309, USA
[3]TERC, 2067 Massachusetts Avenue, Cambridge, Massachusetts 02140, USA
[4]Montana State University, P.O. Box 173480, Bozeman, Montana 59717, USA
[5]City College of San Francisco, 50 Phelan Avenue Box S50, San Francisco, California 94112, USA
[a]Author to whom correspondence should be addressed. Electronic mail: karinkirk@gmail.com. Tel.: 406-582-9084.

and what people are teaching. The CLEAN project also undertook an annual survey to learn about the needs and practices of climate educators. While this information is self-reported, it sheds light on where and how faculty members are focusing their climate education efforts.

CLEAN Informant Group

The CLEAN project employed Inverness Research to create an informant group to provide ongoing information and feedback from the field over 3 y, from 2010–2013. This group was surveyed annually to assess their interest in, concerns about, and needs and practices related to climate literacy and energy awareness. The informant group was drawn from individuals who had an interest in or were already engaged in climate education. Inverness collected approximately 440 e-mail addresses of middle school and high school teachers and lower- and upper-division undergraduate instructors and then sent them an invitation to participate. In addition, the CLEAN management group circulated the invitation to colleagues, professional organizations, and networks. From this widely cast net, 575 people filled out the initial survey. Inverness Research selected 220 participants who represented a range of respondents that looked typical in as many ways as possible.

The initial survey, conducted in January 2011, is the basis for the CLEAN informant survey cited in this paper. This questionnaire sought to characterize the nature of the knowledge, beliefs, and practices of educators that teach about climate and energy. The survey was sent to 220 people, and 213 people completed it, yielding a 97% response rate. The responses were then filtered to include only higher-education faculty members, which yielded 83 respondents. Of these, 70% teach at 4-y institutions, 20% teach at 2-y colleges, 7% were teaching at both a 2-y and a 4-y institution, and 4% were not teaching in 2011. Survey questions were multiple choice, Likert scale, and open response. The multiple-choice and Likert scale questions were used to generate percentages of responses for each answer. The open response questions were read and grouped by emergent categories as recurrent themes became evident in the responses. Categories of responses were then coded and tallied (Patton, 2001).

Workshop Data From CLEAN and On the Cutting Edge

When faculty members applied to attend a workshop, their applications were used for screening, as well as to learn more about the backgrounds and needs of participants. The responses to these questions also provided insights into the types of courses and methods used to teach about climate. For this paper, data from seven climate workshops from 2008–2012 were used, wherein 234 workshop applicants described their current teaching practices.

For the CLEAN climate workshops, applicants were asked about how they teach about climate: "Describe the ways in which you currently teach about climate or hope to teach about climate. Include information about the courses and grade levels in which you teach about climate as well as the climate topics you teach (or are planning to teach)." This question yielded 127 responses over the course of three workshops from 2011–2012.

For On the Cutting Edge workshops, the application questions varied according to the workshop topic, but the responses still yielded similar insights about teaching practices. The questions posed for each workshop are as follows.

- "Please provide a brief description of your teaching and/or research experience with ice core data" (Teaching Climate Change With Ice Core Data, 2008, $n = 47$).
- "What are you already doing to incorporate climate models/data in the classroom? Describe the strategies that you are already using" (Teaching About Earth's Climate Using Data and Numerical Models, 2010, $n = 21$).
- "Please provide a brief description of your teaching and/or research experience with paleoclimate data" (Teaching Climate Change From the Geologic Record, 2010, $n = 22$).
- "Please provide a brief description of your experience with teaching climate science. Include information about the types of courses; grade level and topics" (Teaching Climate Change: Insight From Large Lakes, 2012, $n = 17$).

These responses were used to learn about the types of courses in which climate is taught and the methods used for teaching climate topics. As with the CLEAN informant survey, qualitative analysis was done via coding themes that emerged from the responses (Patton, 2001). Participants who attended more than one workshop were only included in the results from the first workshop they attended so that their responses were not duplicated.

HOW IS CLIMATE CHANGE EDUCATION ADDRESSED IN HIGHER EDUCATION?

Motivations and Support for Teaching About Climate

Results from the 2011 CLEAN survey can shed light on faculty members' motivations for teaching climate topics. Teaching climate science was rated as "high priority" by 59% of respondents. However, the informant group was selected partially on the basis of their interest in climate education, so it is expected that this topic would be important to them. When asked an open-response question about their reasons for teaching climate science, there were clear trends in the responses (Fig. 1). The most common motivation, mentioned by 35% of respondents, was the importance and relevance of climate change. Other prominent responses were the need to raise literacy and create an educated citizenry that is prepared to make informed decisions (17%) and for students to understand the potential impacts of climate change on themselves or on society (17%). Conversely, 10% of the responses mentioned the need for students to understand the impacts of humans on the environment. Many responses contained more than one of these themes:

> *"I feel that the students need to understand the important issues surrounding science today, especially since they have a direct impact/role in the science that is occurring whether they know about it or not. I also often get a lot of interest from students about these topics because most have heard at least something of the controversies out there and they want to know more so that they can make their own educated decisions."*

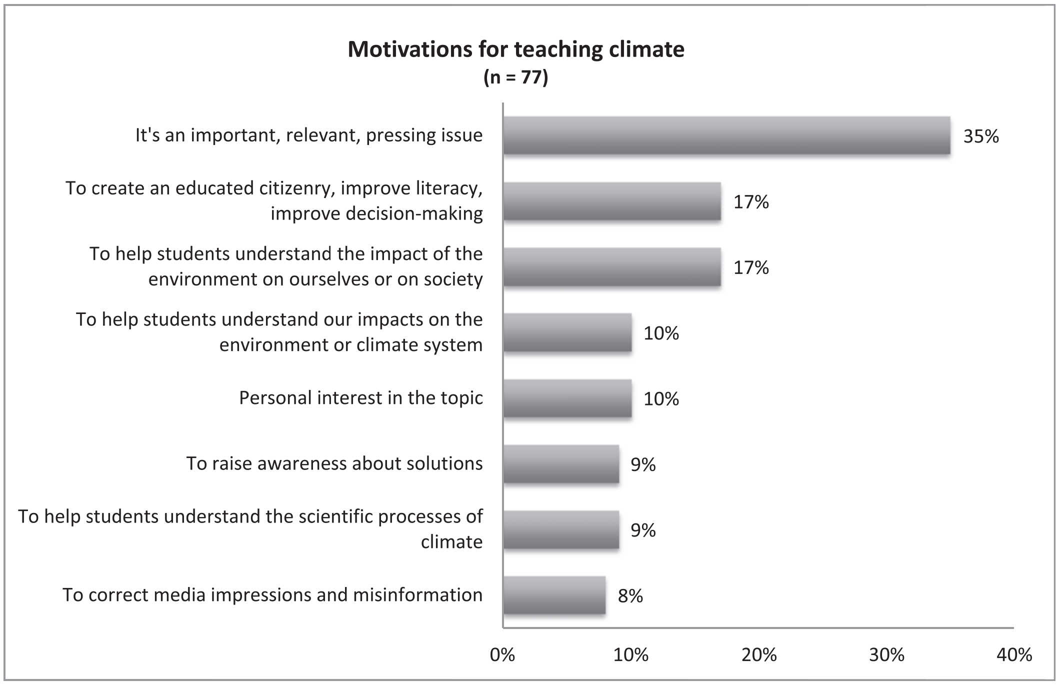

FIGURE 1: Faculty members' motivations for teaching climate.

Additional themes that emerged from the open responses were a desire to strengthen students' scientific understanding of climate processes (9%) and counteract misconceptions and misrepresentations of climate issues in the media (8%):

> *"I teach about climate science and energy awareness in order for my students to become more aware of the science behind these topics and in order for the students to become better critical thinkers when it comes to interpreting what they hear and read from media reports on these topics."*

Faculty members also reported that they endeavor to connect course content to raised awareness and pursuit of solutions (9%):

> *"It is important, in my opinion, to link climate science with energy awareness and choices in order to avoid apathy or a sense of futility in the students. They are much more engaged if they are aware of how they may be able to make a difference."*

On a departmental and institutional level, 46% of respondents felt that teaching of climate science was supported "to a large extent," and 38% felt it was supported to "some extent" (Fig. 2). Many faculty members commented that teaching about climate and energy ties into institutional efforts for energy conservation and sustainability. In a small number of cases (3%), respondents described institutional or departmental resistance to teaching about anthropogenic climate change or other faculty members who "do not accept climate change as factual."

Additional motivation for teaching climate science stems from the need to prepare students for the workforce, as climate literacy is relevant in many disciplines and career pathways. The U.S. Bureau of Labor Statistics (2012) lists climate change as an emerging part of several occupations, including atmospheric scientists, environmental engineers, geographers, hydrologists, wildlife biologists, conservation scientists, accountants, and actuaries.

Climate Is Taught in Many Places Throughout the Undergraduate Curriculum

Workshop applications and CLEAN survey data illuminated how and where applicants teach about climate. By reviewing and coding data from 234 applicants in seven workshops from 2008–2012, a pattern of the undergraduate climate curriculum emerges. Responses to questions about current teaching practices indicated that climate topics are integrated into an array of types of courses and across multiple disciplines. As the climate system touches many other systems and processes integral to society, elements of climate science are intertwined with existing course content and curricula.

Courses dedicated to climate topics are offered at both the introductory level and the upper level. Introductory courses include courses such as Global Climate Change, Geology of Climate Change, Climate Studies, and Climate Change and Energy. Upper-level courses about climate are diverse in their subdisciplines. Courses in climate change and paleoclimatology were the most common upper-level courses in which workshop participants taught about climate. Climate content was also included in courses such as Climate Adaptation, Climate Change and Land Use, Oceans and Climate, and Weather and Climate. In addition to stand-alone climate courses, faculty members reported that they weave climate topics into other courses where appropriate. Respondents indicated that climate-related content is a significant part of many traditional introductory-level and upper-level courses in the Earth Sciences and related disciplines. Data from the CLEAN informant pool showed that 43% of respondents "always" or "mostly"

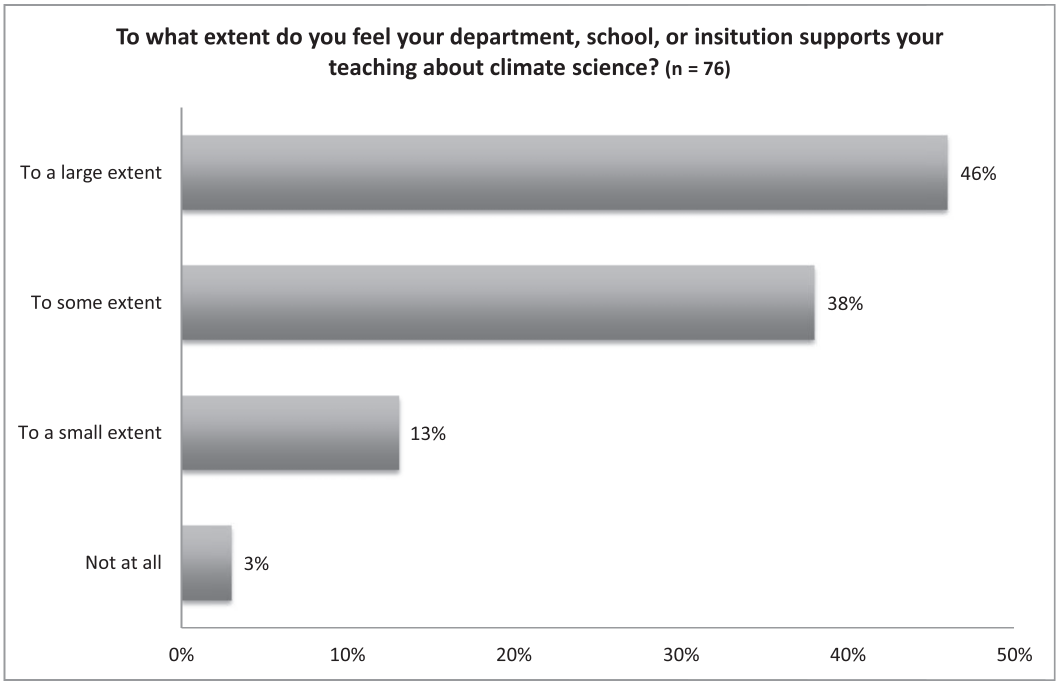

FIGURE 2: Support of teaching of climate science by departments, schools, or institutions.

integrate climate topics into other course content, while 38% use an equal mix of stand-alone and integrated approaches while teaching climate topics (Fig. 3).

Reaching beyond the realm of the geosciences, workshop applicants described the role of climate topics in courses such as Ecological Commerce, Coastal Change, Environmental Biology, City Science, and Quaternary Biology. In addition, specialized climate courses are taught specifically for preservice and in-service teachers to provide a foundation for teaching climate science to a younger audience.

A majority (53%) of CLEAN informant pool respondents report that they place equal focus on the scientific aspects and the societal implications of climate science and energy awareness (Fig. 4). One respondent described the integration of policy and science in the use of case studies where students work in teams to study a specific problem, present solutions, and discuss and vote on various proposals. Another example involved a collaboration of a science professor and an ethics professor to allow both science students and ethics students to benefit from an alternative perspective and to help "students understand the different roles science and ethics play in making decisions about climate change."

These results, while not exhaustive, are useful to illustrate the breadth and depth that climate education has attained in the undergraduate setting. Most faculty members are working in an environment that is supportive of teaching about climate, are motivated to inform students of the relevance and impacts of climate change, and are integrating climate science in flexible and innovative ways.

SUCCESSFUL STRATEGIES FOR TEACHING

Climate change is a complex, challenging, and potentially contentious topic (Leiserowitz et al., 2010; McCright and Dunlap, 2011), thus effective teaching approaches are especially important. Our data show that educators are looking for helpful, novel, and engaging strategies for their instruction. Common themes in workshop applications are "I want to be more effective in teaching climate change," "I want new approaches for bringing data and exciting science to my students," or "I'd like to motivate my students without scaring them or being the doomsayer." A theme of the On the Cutting Edge program is to build on the success of our community and learn from what is working for others (Manduca et al., 2010). In that vein, we describe a variety of pedagogic methods that were reportedly successful in the CLEAN informant survey and have been showcased at CLEAN and On the Cutting Edge workshops.

Many Types of Successes Are Occurring

Climate change is a complex subject that requires the understanding of many physical processes (IPCC, 2013). The implications of a changing climate on humans results in strong public interest in the topic (Corner et al., 2014). The CLEAN informant pool illustrates this, with 25% of respondents describing strong student interest and high demand for climate courses among their noteworthy successes. This high interest level can be leveraged in many ways, offering avenues for exploration, inquiry, and thoughtful pedagogy.

When CLEAN informant pool was asked about notable successes they have had over the past 3 y, the responses shed light on what they feel are the most productive teaching strategies. Frequent responses emerged around the themes of using the local environment to learn about nearby climate impacts, creating active classroom experiences such as structured discussion or role playing, or using "hands-on" lab activities. When the responses were coded, 12 approaches using active pedagogies were described. In some cases, more than one technique was used by a single educator. This

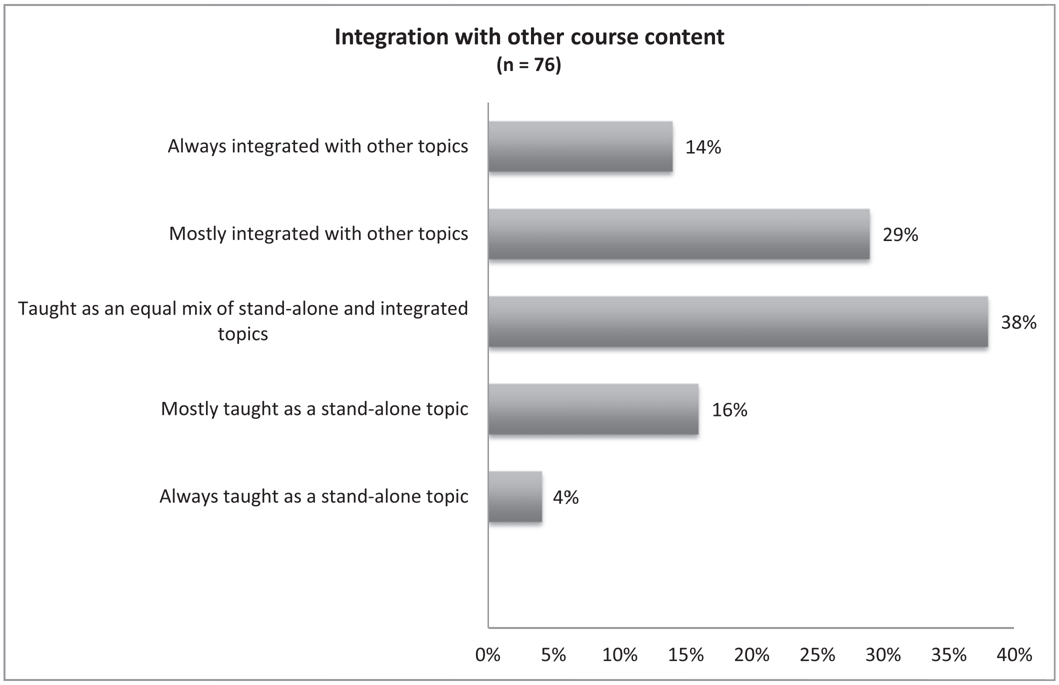

FIGURE 3: Integration of climate topics with other course content.

list highlights active learning techniques that were used, with the number of respondents for each approach in parentheses:

- Local emphasis or local data (9)
- Presentations and engaging in structured discussion (6)
- Hands-on labs (6)
- Google Earth and other forms of remote sensing and computer-based mapping (4)
- Debates, town hall–style meetings, and role playing (4)
- Working with real data (not necessarily local data) (3)
- Inquiry-driven learning techniques (3)
- Using case studies to examine the effects of climate change in different parts of the world (2)
- Using news stories to engage students in current climate topics and issues (1)
- Fieldwork (1)

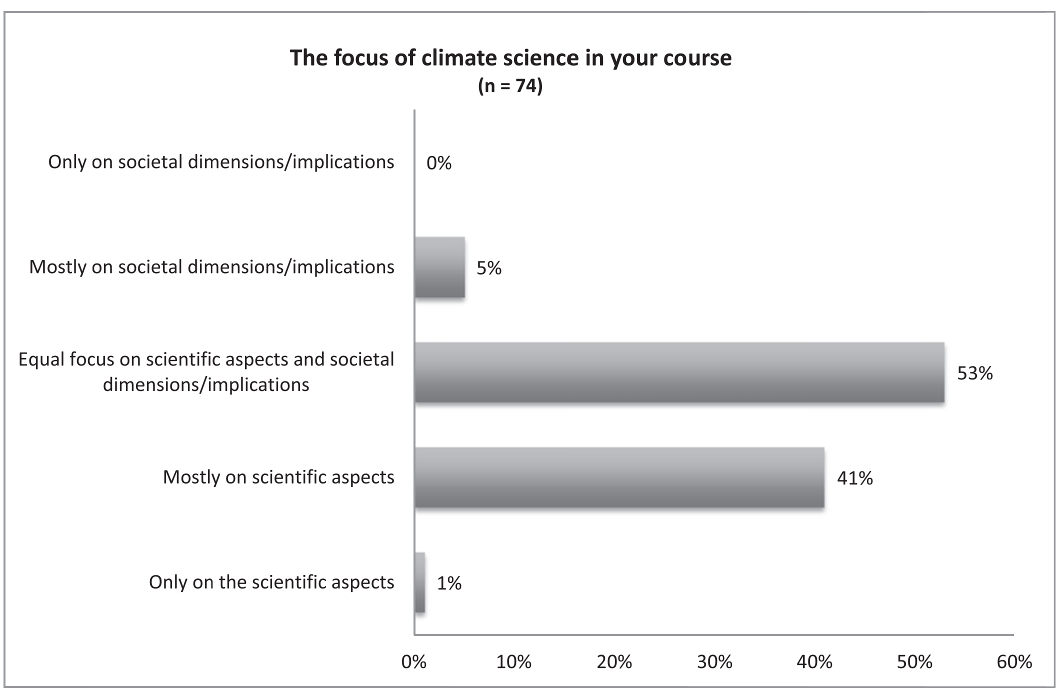

FIGURE 4: The focus of climate science topics in courses.

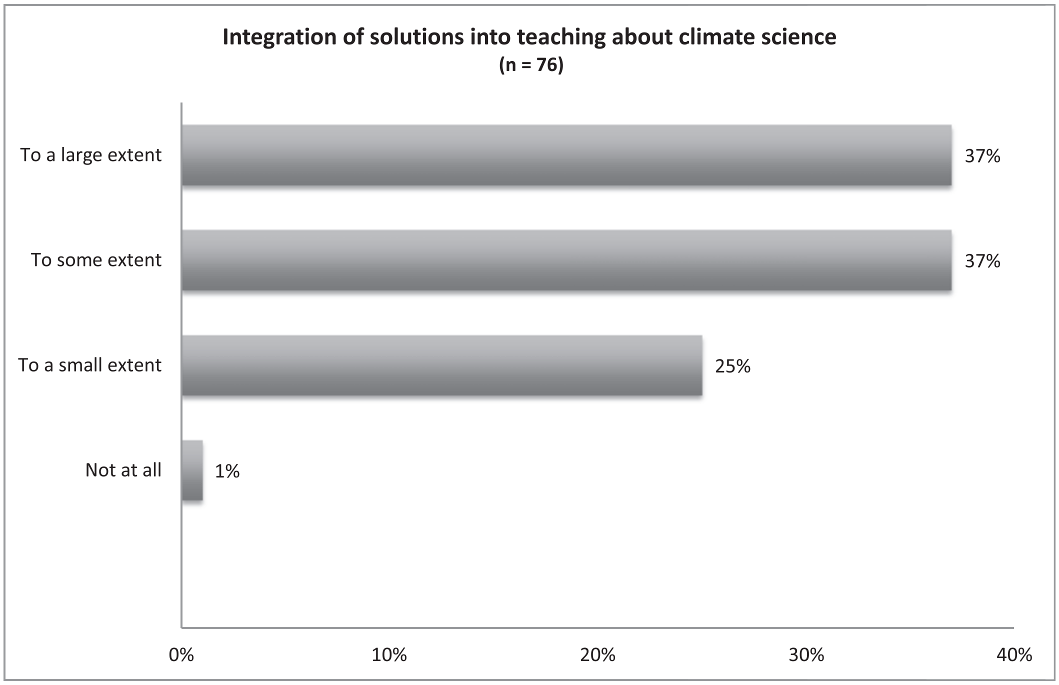

FIGURE 5: Integration of solutions into teaching about climate science.

- Citizen science (1)
- Modeling (1)

Active pedagogies have shown to be effective in engaging students in a topic (Hake, 1998; McConnell et al., 2003; Prince, 2004), and these results suggest that faculty members are incorporating a variety of instructional techniques to go beyond the lecture to explore some of the many facets of climate change.

Focusing on Solutions

The Guiding Principle of the Climate Literacy Principle states: "Humans can take action to reduce the effects of climate change" (U.S. Global Change Research Program, 2009). To what extent are our students learning about why and how they can take action? From the CLEAN informant pool, 37% of faculty members reported that they integrate climate change solutions "to a large extent," with another 37% reporting "some" integration of solutions (Fig. 5). When asked to report notable teaching successes, strategies involving solutions were described in 29% of the responses. These solutions range in scales from the personal level with carbon footprint analyses or the Lifestyle Project (Kirk and Thomas, 2003), to the campus level by evaluating and proposing energy-saving initiatives, and to the community and national level by incorporating role-playing activities and adopting the perspectives of various stakeholders. One respondent summed up how solutions can tie into course content to help build students' enthusiasm for the topic:

> *"The greatest successes come when I see students making the connections from whatever subject area we are discussing to climate science and energy awareness. I get extra excited when students learn that they can make a difference and they get excited enough to take the steps to make those changes. Many go on to major or at least take additional classes that discuss these issues."*

While it's much harder to observe and quantify, faculty members reported that their students are changing their behavior as a result of learning about climate and/or energy in their courses. Nearly half (49%) of the faculty members surveyed as part of the CLEAN informant pool felt that their students have changed their behavior to "some extent" or to "a large extent" following instruction about climate topics (Fig. 6). Respondents described students who participate in energy-saving competitions, eat locally grown food, grow a vegetable garden on campus, increase their walking and bicycle riding, and reduce classroom waste. Similarly, a majority (77%) of CLEAN informants think their students are using their knowledge of these issues more broadly in discussions with classmates, friends, family members, or even strangers (Fig. 7). One respondent wrote:

> *"I have many students come tell me about ways lectures and labs have changed their minds, and how discussions on such information with friends, family, and strangers on ski lifts used that information."*

Using the Local Context Makes Climate Change More Relevant

While climate change is often incorrectly perceived at having consequences that only affect far-off locales at some time in the distant future (Leiserowitz, 2005), the reality of climate change can become more relevant and engaging if students are exposed to climate systems and climate impacts in their backyard. At the 2012 On the Cutting Edge workshop Teaching Environmental Geology, a theme session was held to explore how to teach environmental topics in the local environment. The related collection of

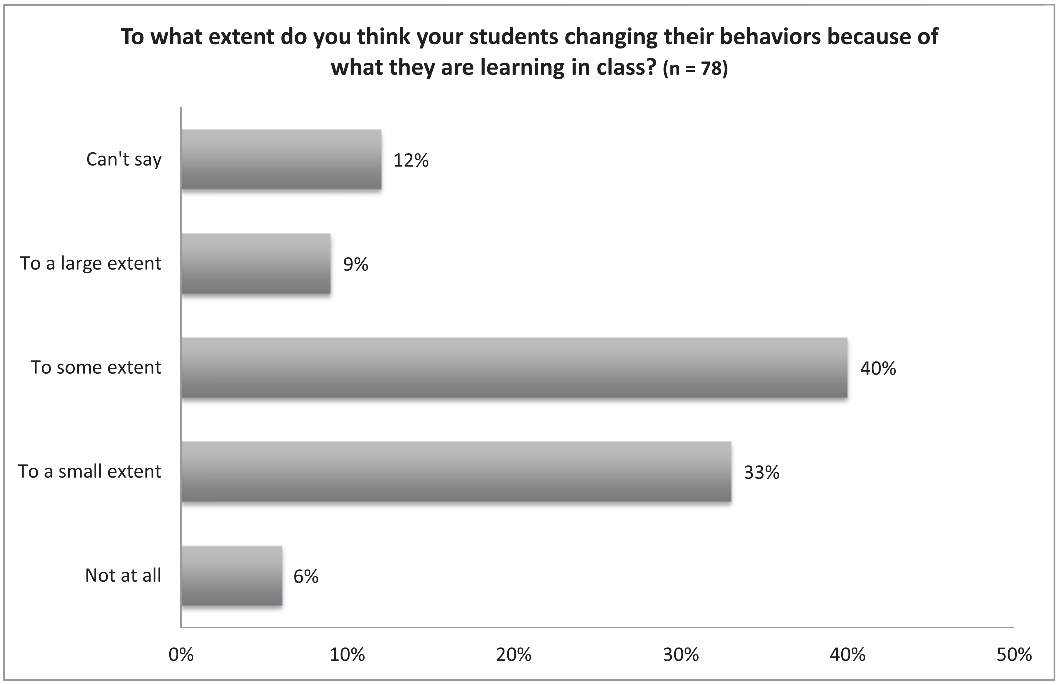

FIGURE 6: Self-reported answers about students' behavior changes as a result of what they've learned in class.

climate activities written and submitted by college faculty members contains 63 activities that use a connection with local climate data, climate impacts, or activities that contribute to climate change. Examples include calculating the campus greenhouse gas inventory, comparing temperature records for several cities across the U.S., assessing local sea-level rise, and exploring local, regional, and seasonal hydrology.

Examining climate processes and impacts via the local environment was a common theme in the CLEAN informant pool survey as well, with 46% of faculty members reporting that studying a local issue is a type of learning students would be most interested in and 11% of respondents listing a local or community-based emphasis among their notable successes. Faculty members described how they used a local context to teach about climate processes, climate history, and

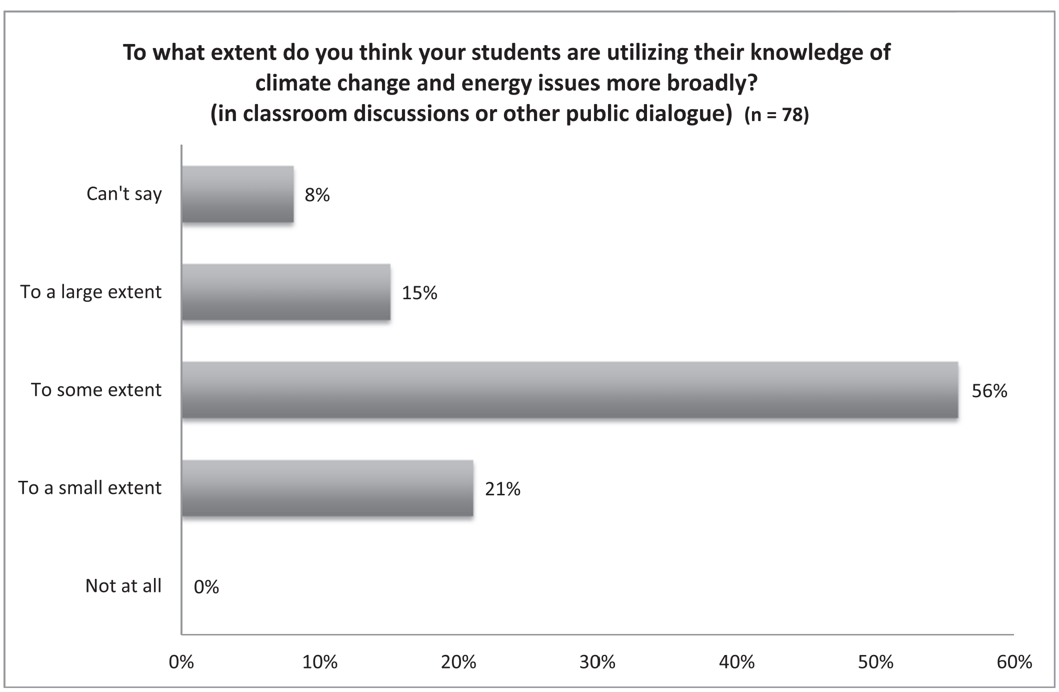

FIGURE 7: Students' use of climate and energy knowledge in broader ways, such as in classroom discussions or other dialogues.

impacts of climate change. In some cases this involved detailed spreadsheet analysis of past, present, and future temperatures, and in other cases the approach involved using the local setting as a framework for examining potential solutions. A CLEAN survey respondent described the educational value of the local setting:

> *''I am very interested in helping students recognize signs of climate change in their local areas to increase both their awareness of the impact and their interest in learning more and becoming active.''*

Teaching With Data Illuminates the Process of Science

Authentic datasets are a natural fit for teaching about Earth's climate system (Ledley et al., 2011; Taber et al., 2012). Numerous datasets are freely available to investigate many aspects of climate, such as atmospheric carbon dioxide concentrations, ice core data, temperature records, emissions trends, and energy use. In the CLEAN informant survey, 69% of respondents reported they use real scientific data to teach about climate science.

Engaging students with data has benefits in many types of science instruction, but given the controversial nature of climate science, exposing students to the process of scientific inquiry and the methodology used to analyze data are particularly relevant. Manduca and Mogk (2002) summarize the benefits of data-enhanced learning experiences, and these outcomes overlap especially well with the motivations that faculty members describe for teaching climate science:

- *''Prepare students to address real-world complex problems;*
- *Develop students' ability to use scientific methods, including consideration of the values and ethics of working with data;*
- *Teach students how to critically evaluate the integrity and robustness of data or evidence and of their consequent interpretations or conclusions; and*
- *Provide training in scientific, technical, quantitative, and communication skills'' (Manduca and Mogk, 2002).*

Because of the importance of teaching with data, the CLEAN collection of educational resources provides a search feature that displays teaching materials that rely on scientific datasets. This subcollection currently contains 72 activities for teaching introductory-level climate topics and 32 resources for teaching upper-level climate science. Similarly, the On the Cutting Edge collection features a data-rich subcollection that contains 36 resources for teaching climate science, along with pedagogic support, teaching ideas, and tools for bringing data-based activities into the undergraduate classroom.

Controversy Is Part of Teaching About Climate

Faculty members understand that teaching about anthropogenic climate change can be challenging because of prevailing misconceptions, misinformation, and political and cultural pushback (McCaffrey and Buhr, 2008; Lombardi and Sinatra, 2012). Thus, many educators have developed particular strategies for effective teaching, and workshops from CLEAN and On the Cutting Edge have provided specific training for managing both the cognitive and affective aspects of teaching climate change.

Presenting students with controversial topics may stir up values, judgments, biases, and emotions. On one hand, controversy is interesting and engaging, but on the other, faculty members are advised to avoid reinforcing the misperception that there is dispute within the scientific community about the basis for anthropogenic climate change (Bedford, 2010). The On the Cutting Edge project explored the role of the affective domain with respect to teaching about controversial topics such as climate change and evolution. Active learning strategies were emphasized, such as role playing or working directly with data, so that students can create their own understanding of controversial topics, (Iozzi, 1989; Schweizer and Kelly, 2005). Faculty members understand the need to be clear about their role in the classroom and to carefully consider whether to incorporate policy discussions into a science course or to advocate for certain positions (Corney, 1998). Where lifestyle choices and behaviors are concerned, faculty members are well served by focusing on (and participating in) active solutions rather than preaching desired behaviors to the class (Kirk and Thomas, 2003).

Leiserowitz (2005) points out that for the public, factors like cultural values, social norms, and worldview can play a large role in perception of climate change. Thus, it can be helpful to guide students through activities that can show them how to balance competing values. A pedagogic technique called structured academic controversy (Khourey-Bowers, 2006) was demonstrated at the 2007 On the Cutting Edge workshop titled Student Motivations and Attitudes: The Role of the Affective Domain in Geoscience Learning. This method was developed for teaching evolutionary theory but is also suited for teaching about climate change (Khourey-Bowers, 2008). The technique explores the idea that controversy does not need to be equated with conflict. The author stresses that while teaching controversial topics that have strong cultural ties, students do not need to make a ''dichotomous choice'' from among multiple viewpoints (Khourey-Bowers, 2006). Structured academic controversy engages students in role playing but with a goal of considering multiple perspectives and seeking a consensus rather than having one side win and another side lose. The learning outcomes for this format are ''to expand individuals' perspectives and understanding of others' points of view; and to develop deeper understanding of the complexities of climate change'' (Khourey-Bowers, 2008).

The range of values over climate change can be further highlighted by activities that employ role playing, negotiations, and opportunities for students to consider the points of view of diverse stakeholders. These pedagogic strategies were frequently described by CLEAN informants and by On the Cutting Edge and CLEAN workshop participants. Effective use of these activities allows for an understanding that values, emotion, and affect play a role in understanding climate impacts and climate policy and thus can help ease the divide that has arisen around climate change.

Communication Strategies Can Help Clarify Misconceptions

Perhaps more than most college-level topics, effective communication is an essential part of teaching climate science (Moser, 2010). This is especially true given the poor knowledge and abundant misconceptions students hold on this topic before starting formal instruction (Leiserowitz et al., 2011a). The task of identifying and unraveling misconceptions, communicating the scientific concepts without painting a picture of dire consequences of a warming world, and parsing scientific facts from political positions present particular challenges for the climate educator (Moser, 2010).

A 2012 CLEAN workshop aimed to equip faculty members with purposeful communication strategies for teaching climate change. A key to effective communication is the understanding that different people process the same information in different ways. ''The facts are actively interpreted by these different audiences, who construct their own mental models in accordance with what they 'know,' value, and feel. Knowledge is necessary, but insufficient'' (Leiserowitz et al., 2010). This resonates with classroom teaching because it underscores that students do not process new information in a uniform way; rather, new ideas are actively interpreted according to the existing knowledge and values of the listener. Educators can thus fine-tune their message to suit their particular audience and be vigilant for differences in how students perceive information.

An abundance of misconceptions and misinformation about climate change has infused our societal consciousness, yielding a population that ranges from extreme concern over climate change to denial that it even exists (McCaffery and Buhr, 2008; Leiserowitz et al., 2009). Climate misconceptions can have many root causes. Some misconceptions are largely cognitive, such as a misunderstanding of the role of the ozone layer in absorbing ultraviolet solar radiation and preventing it from reaching the Earth's surface. But misconceptions can also be intertwined with one's worldview (Cook and Lewandowsky, 2011). For example, even though there is strong consensus among climate scientists about the causes of anthropogenic climate change (Cook et al., 2013), there has been much public resistance to the idea that humans are altering the climate, particularly among those who are politically conservative (Leiserowitz et al., 2011b).

The underlying cause of a student's misunderstanding determines the path taken to address it. A ''simple'' cognitive misconception can be addressed using pedagogies such as creating cognitive conflict, using argument to strengthen newly acquired information, and/or raising student metacognition (Lucariello, 2009). But worldview misconceptions are persistent, and research has shown that attempts to correct misinformation that is in conflict with one's worldview can actually serve to reinforce it (Nyhan and Reifler, 2010). So where does that leave educators? Cook and Lewandowsky (2011) note that creating a setting that boosts self-affirmation allows people to be more balanced in how they perceive new information. Moreover, potentially confrontational information can be received more readily if it is framed in a way that it will not conflict with people's worldview. Kahan et al. (2007) advise identifying the worldview of the intended audience and ''crafting an appeal that affirms rather than denigrates recipients' values.'' For example, while public opinion research shows considerable disagreement about climate change, it also reveals alignment between disparate groups when asked about energy-saving measures (Leiserowitz et al., 2009).

In the 2012 CLEAN climate communication workshop, Dr. Daniel Bedford demonstrated a head-on approach in tackling climate misinformation. His approach, called agnotology, involves the deliberate use of misinformation as a teaching tool (Bedford, 2010). As a capstone activity in a climate science course, students read Michael Crichton's *State of Fear* and summarized and critiqued some key points of the book. By examining misinformation at the end of the course, students were able to consider the fictional work in light of their understanding of climate science and the process of scientific inquiry. Students compared Crichton's work to Oreskes (2004) summary of the peer-reviewed literature and had an opportunity to strengthen their understanding of climate concepts and apply critical-thinking skills to distinguish the flaws in the scientific arguments. When this technique was used as a demonstration at the workshop, faculty members took particular delight in debunking the example text, and the workshop sparked collaboration among participants to produce further research on this topic (Cook et al., in press).

By infusing climate topic into the curriculum, employing rich and innovative teaching methods, and being mindful of cognitive and affective challenges, faculty members have reported success in reaching their students. In the CLEAN informant study, faculty members described increased student understanding of the science behind climate change, reduced skepticism, increased awareness of how to take action, and a high level of student interest in the course topics. Furthermore several faculty members reported that their climate courses have become increasingly popular and have measured increasing enrollments. Results such as these are encouraging, showing that educators feel they are successfully engaging their students with climate topics.

SUPPORTING FACULTY MEMBERS WHO TEACH CLIMATE CHANGE

Effective climate education relies on the expertise of many types of professionals. There is a need for collaborative input from scientists (who provide reliable science and data), instructors and curriculum developers (who design, test, and review teaching activities), learning scientists (who illuminate affective and cognitive components), and professional development programs and networks (offering workshops, Web spaces with aggregated community advice, virtual journal clubs, and e-mail lists that provide continuing support for climate education). The CLEAN and On the Cutting Edge projects strive to facilitate this collaboration. These programs offer many pathways to support faculty members and to create a network of educators who can build off of one another's successes to strengthen teaching and develop avenues for science outreach. Below we describe the rationale and design for different workshop types.

Workshops

The CLEAN project offered three online workshops for faculty members who teach climate science. The goals of the workshops were to give faculty members opportunities to explore and use the CLEAN Collection of teaching materials, showcase research about climate topics and pedagogy, improve the content knowledge of participants, demonstrate examples of successful methods and activities for teaching about the climate system, and provide a forum for collaboration in developing new teaching resources.

Because these workshops were free to attend and were held online with no travel requirements, the barrier to participation was low. A total of 69 educators completed one or more of the online workshops, hailing from traditional 4-y colleges, 2-y colleges, professional development programs, and informal education programs. The online format also made it realistic to invite expert speakers from faraway locations. Keynote presenters included Richard Alley, John Cook, Anthony Leiserowitz, and David Archer, and the format allowed for both formal presentations and informal discussion.

Faculty members were exposed to exemplary teaching activities by taking part in online demonstrations led by the authors of these activities. Activities included plotting Mauna Loa carbon dioxide data, running a simplified mass balance model, and participating in role-playing activities about international climate policy. Finally, workshop participants collaborated to create new teaching materials, with a particular emphasis on addressing pedagogic challenges related to the workshop topic. Faculty members collaborated to produce 17 activities during CLEAN workshops, ranging from a suite of activities to teach different aspects of the greenhouse effect to classroom strategies for debunking common climate myths. Webcasts and PowerPoint files of the presentations and teaching materials are freely available at http://CLEANet.org/CLEAN/community/workshops.

From 2006 through 2013, On the Cutting Edge hosted seven professional development activities related to climate education. Beginning in 2006, On the Cutting Edge partnered with the American Quaternary Association (AMQUA) to host 1-d workshops aligned with AMQUA's biannual conference. Since 2008, each AMQUA meeting has incorporated a scientific theme, and these themes were adopted for the pedagogic workshop. The themes were teaching with ice core data (2008), teaching climate change from the geologic record (2010), and teaching climate with data from large lakes (2012). Faculty members and scientists explored ways to use those ideas in undergraduate education and collaborated to generate ideas for teaching climate.

On the Cutting Edge also held stand-alone workshops focusing on climate topics, such as The Hurricanes–Climate Change Connection (2008), Teaching About Earth's Climate Using Data and Numerical Models (2010), and the Climate and Energy Webinar and Book Club Series (2011). Of these seven workshops, four were used to gather information about teaching practices as described earlier in this paper. The remaining three did not have questions on the workshop application that were suitable for comparison across workshops.

In all, more than 150 participants attended these events and contributed to the creation of 20 teaching activities and 23 ideas for teaching climate science. Materials and presentations from these workshops can be found at http://serc.carleton.edu/NAGTWorkshops/climatechange.

While this paper focuses on just two programs, a host of other professional development programs are also striving to improve climate literacy. The Tri-Agency Climate Education catalog offers a searchable listing of educational programs at https://nice.larc.nasa.gov/trace/trace_catalog.php.

Web Sites

In addition to hosting the work produced at the workshops, the CLEAN (http://CLEANet.org) and On the Cutting Edge (http://serc.carleton.edu/NAGTWorkshops) Web sites provide an ongoing mechanism for faculty members to learn about climate pedagogy, see what their peers are doing, and gather materials and ideas adaptable to their courses. The CLEAN informant pool research indicated that faculty members prefer to create teaching materials by assembling components into a new resource from a variety of trusted sources. Both the CLEAN and On the Cutting Edge Web sites support this process by organizing credible materials in freely accessible platforms. In both cases, activities are in a standardized format, allowing for efficient browsing. Materials are sortable by topic, subtopic, grade level, and type of resource. There are 387 college-level teaching activities relating to climate science in the On the Cutting Edge collection and 438 college-level resources in the CLEAN collection.

The entire CLEAN collection has been through a rigorous review process described by Gold et al. (2012). This process screens for scientific accuracy, pedagogic robustness, and ease of use. As a result, faculty members can be assured that materials meet high standards for scientific and pedagogic excellence.

Similarly, the On the Cutting Edge project is engaged in a review process for more than 1800 activities in collections across many geoscience disciplines. Reviewers are assessing teaching activities for (1) scientific veracity; (2) alignment of learning goals, activity, and assessment; (3) pedagogical effectiveness; (4) usability; and (5) completeness of the activity's Web page. As a result, there are 330 activities in the exemplary collection to date, 28 of which are related to climate science.

CONCLUSIONS

The scientific complexity, societal implications, and political associations around climate change make it a difficult and important topic to teach. Faculty members are rising to meet this challenge and are actively engaged in effectively educating students to become scientifically literate citizens. Successful approaches are underpinned by the recognition that thoughtful and engaging pedagogies are particularly useful when teaching about climate change. Those approaches include several strategies to create active learning experiences, navigate misconceptions, and correct misinformation. Projects such as CLEAN and On the Cutting Edge are working to support and strengthen teaching of climate change by creating opportunities for faculty members to hear from experts in the field and to collaborate on the creation, refinement, or review of teaching materials. These project Web sites provide free access to high-quality, searchable collections of teaching materials so that the educational community can benefit from and build upon this work. While this paper presents a summary of available self-reported data to characterize successes in undergraduate climate education, the authors recommend further research to help identify the most robust and useful approaches and to gain a deeper understanding of educational solutions for this complex challenge.

Most importantly, these educational efforts must persist. The scientific and societal challenges faced by the next generation will require a widespread foundation of climate literacy. It is our hope that current endeavors lead to further innovations and successes that will not only engage students but will also benefit society at large.

Acknowledgments

CLEAN is funded by grants from the National Oceanic and Atmospheric Administration (NOAA; NA12OAR4310143, NA12OAR4310142), the National Science Foundation (NSF) Division of Undergraduate Education (DUE) (DUE-0938051, DUE-0938020, DUE-0937941) and the Department of Energy. On the Cutting Edge is supported by the NSF DUE under grants 0127310, 0127141, 0127257, 0127018, 0618482, 0618725, 0618533, 1022680, 1022776, 1022844, and 1022910. We acknowledge the thorough work Inverness Research did in administration and analysis of the CLEAN informant pool. We thank all participants for their constructive feedback and reflection. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the NSF, NOAA, or Department of Energy.

REFERENCES

Bedford, D. 2010. Agnotology as a teaching tool: Learning climate science by studying misinformation. *Journal of Geography,* 109(4):159–165.

Cook, J., Bedford, D., and Mandia, S. 2014. Raising climate literacy through addressing misinformation: Case studies in agnotology-based learning. *Journal of Geoscience Education,* 62(3):296–306.

Cook, J., and Lewandowsky, S. 2011. The debunking handbook, 2nd ed. St. Lucia, Australia: University of Queensland.

Cook, J.J., Nuccitelli, D., Green, S.A., Richardson, M., Winkler, B., Painting, R., Way, R., Jacobs, P., and Skuce, A. 2013. Quantifying the consensus on anthropogenic global warming in the scientific literature. *Environmental Research Letters,* 8(2):024024.

Corner, A., Markowitz, E., and Pidgeon, N. 2014. Public engagement with climate change: The role of human values. *Wiley Interdisciplinary Reviews: Climate Change,* 5(3):411–422.

Corney, G. 1998. Learning to teach environmental issues. *International Research in Geographical and Environmental Education,* 7(2):90–105.

Gold, A.U., Ledley, T.S., Buhr, S.M., Fox, S., McCaffrey, M., Niepold, F., Manduca, C., and Lynds, S.E. 2012. Peer-review of digital educational resources: A rigorous review process developed by the Climate Literacy and Energy Awareness Network (CLEAN). *Journal of Geoscience Education,* 60(4):295–308.

Hake, R. 1998. Interactive-engagement versus traditional methods: A six-thousand–student survey of mechanics test data for introductory physics courses. *American Journal of Physics,* 66:64–74.

Hamilton, L.C. 2011. Education, politics and opinions about climate change evidence for interaction effects. *Climatic Change,* 104(2):231–242.

Iozzi, L.A. 1989. What research says to the educator, part 2: Environmental education and the affective domain. *Journal of Environmental Education,* 20(4):6–13.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate change 2013: The physical science basis. 5th assessment report. Available at https://www.ipcc.ch/report/ar5/wg1/.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014: Impacts, adaptation, and vulnerability. 5th assessment report. Available at https://www.ipcc.ch/report/ar5/wg2/.

Kahan, D., Braman, D., Gastil, J., Slovic, P., and Mertz, C.K. 2007. Culture and identity-protective cognition: Explaining the white male effect in risk perception. *Journal of Empirical Legal Studies,* 4(3):465–505.

Khourey-Bowers, C. 2006. Structured academic controversy: A peaceful approach to controversial issues. *American Biology Teacher,* 68(5):43–47.

Khourey-Bowers, C. 2008. Structured academic controversy: Climate change—*Pedagogy in Action* at the Science Education Resource Center. Available at http://serc.carleton.edu/29333 (accessed 12 June 2013).

Kirk, K.B., and Thomas, J.J. 2003. The lifestyle project. *Journal of Geoscience Education,* 51(5):496–499.

Ledley, T.S., Dahlman, L., McAuliffe, C., Haddad, N., Taber, M., Domenico, B., Lynds, S., and Grogan, M. 2011. Making earth science data accessible and usable in education. *Science,* 333(6051):1838–1839.

Leiserowitz, A. 2005. American risk perceptions: Is climate change dangerous? *Risk Analysis,* 25(6):1433–1442.

Leiserowitz, A., Maibach, E., Roser-Renouf, C., and Hmielowski, J.D. 2011b. Politics and global warming: Democrats, Republicans, independents, and the Tea Party. Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change Communication.

Leiserowitz, A., Smith, N., and Marlon, J.R. 2009. Global warming's six Americas. Yale University. New Haven, CT: Yale Project on Climate Change Communication.

Leiserowitz, A., Smith, N., and Marlon, J.R. 2010. Americans' knowledge of climate change. Yale University. New Haven, CT: Yale Project on Climate Change Communication.

Leiserowitz, A., Smith, N., and Marlon, J.R. 2011a. American teens' knowledge of climate change. Yale University. New Haven, CT: Yale Project on Climate Change Communication.

Lombardi, D., and Sinatra, G.M. 2012. College students' perceptions about the plausibility of human-induced climate change. *Research in Science Education,* 42(2):201–217.

Lucariello, J. 2009. How do I get my students over their alternative conceptions (misconceptions) for learning? American Psychological Association. Available at http://www.apa.org/education/k12/misconceptions.aspx (accessed 12 June 2013).

Manduca, C.A., and Mogk, D.W. 2002. Using data in undergraduate science classrooms. Final report on an interdisciplinary workshop held at Carleton College, April 2002. Northfield, MN: Carleton College, Science Education Resource Center.

Manduca, C.A., Mogk, D.W., Tewksbury, B., Macdonald, R.H., Fox, S.P., Iverson, E.R., Kirk, K., McDaris, J., Ormand, C., and Bruckner, M. 2010. On the Cutting Edge: Teaching help for geoscience faculty. *Science,* 327(5969):1095–1096.

McCaffrey, M.S., and Buhr, S.M. 2008. Clarifying climate confusion: Addressing systemic holes, cognitive gaps, and misconceptions through climate literacy. *Physical Geography,* 29(6):512–528.

McConnell, D.A., Steer, D.N., and Ownes, K.D. 2003. Assessment and active learning strategies for introductory geology courses. *Journal of Geoscience Education,* 51:205–216.

McCright, A.M., and Dunlap, R.E. 2011. The politicization of climate change and polarization in the American public's views of global warming: 2001–2010. *Sociological Quarterly,* 52(2):155–194.

Moser, S.C. 2010. Communicating climate change: History, challenges, process and future directions. *Wiley Interdisciplinary Reviews: Climate Change,* 1(1):31–53.

National Climate Assessment (NCA). 2014. Climate change impacts in the united states: Highlights and full report. Available at http://nca2014.globalchange.gov/ (accessed 16 July 2014).

Nyhan, B., and Reifler, J. 2010. When corrections fail: The persistence of political misperceptions. *Political Behavior,* 32(2):303–330.

Oreskes, N. 2004. The scientific consensus on climate change. *Science,* 306(5702):1686.

Patton, M., ed. 2001. Qualitative research and evaluation methods, 3rd ed. Thousand Oaks, CA: Sage.

Prince, M. 2004. Does active learning work? A review of the research. *Journal of Engineering Education,* 93:223–231.

Schweizer, D.M., and Kelly, G.J. 2005. An investigation of student engagement in a global warming debate. *Journal of Geoscience Education,* 53(1):75–84.

Sullivan, S.B., Ledley, T.S., Lynds, S.E., and Gold, A.U. Navigating climate science in the classroom: Teacher preparation, perceptions and practices. *Journal of Geoscience Education,* in press.

Taber, M.R., Ledley, T.S., Lynds, S., Domenico, B., and Dahlman, L. 2012. Geoscience data for educational use: Recommendations from scientific/technical and educational communities. *Journal of Geoscience Education,* 60(3):249–256.

U.S. Bureau of Labor Statistics. 2012. Occupational outlook handbook, 2012–2013 ed. Available at http://www.bls.gov/ooh (accessed 3 June 2013).

U.S. Global Change Research Program. 2009. Climate literacy: The essential principles of climate sciences. Available at http://pmm.nasa.gov/education/sites/default/files/article_images/Climate%20Literacy%20Booklet%20Hi-Res.pdf (accessed 16 July 2014).

Wegner, G.R. 2008. Partnerships for public purposes: Engaging higher education in societal challenges of the 21st century. National Center for Public Policy and Higher Education. Available at http://www.highereducation.org/reports/wegner/wegner.pdf (accessed 16 July 2014).