An Exploration of Ideas Related to the Understanding and Teaching of Climate Science and Climate Change

Published: September 13, 2018

Compiled by
Eric Pyle, Frank Niepold, Don Haas, Michael Wysession, and Cheryl Manning

The following document was compiled by select members of a team that developed the NSTA position statement, *The Teaching of Climate Science (NSTA 2018)*. It expands on five important ideas related to the understanding and teaching of climate science. This document is intended to provide additional exploration and insights. The views and information provided belong to the authors noted above.

1. The Nature of Science (NOS) and Scientific Decision-Making

The *Framework for K–12 Science Education* (*Framework;* NRC 2012), developed by the National Research Council, provides a sound, evidence-based foundation for science education grounded in scientific research—including the study of climate science. The *Next Generation Science Standards* (*NGSS; NGSS* Lead States 2013), based on the NRC *Framework*, support the teaching of climate change, which is explicitly included as part of the "Big Ideas" of Earth and space science. The *NGSS* have been fully adopted by 19 states and the District of Columbia, representing more than 36% of U.S. students, and 20 more states have adapted similar standards based on the *Framework*. For the first time, climate change is recommended as a core concept for science curricula for both middle school and high school, including an emphasis on "human-induced" effects.

Efforts to properly teach the science of climate change are regularly challenged by those seeking to frame it as being different than other scientific fields, often with claims that it is either "uncertain" or "controversial." They advocate the need for a special approach to teaching climate science that includes such efforts as "balancing" alternative perspectives through debates and false equivalences. It is important that a distinction be made between scientific debate and unscientific denial. There is always scientific debate in any area of science, but there is also a much greater amount of scientific consensus about that field's fundamental understandings; the same holds true for climate science. There is no scientific controversy about the central findings of climate scientists indicating that world climates are rapidly changing, that these changes are largely driven by human activities, are a serious threat to society and ecosystems, and that rapid reductions in emissions of CO_2 are necessary to limit near-term climate change and long-term warming (USGCRP 2017). Any controversies about these fundamental observations come from social, economic, or political domains, but not from the scientific community. While it is possible to find individual scientists who disagree with the scientific consensus, they are a tiny minority, and their positions do not warrant equal consideration or equal time. Those individuals with scientific credentials who reject the consensus on climate change typically do not have expertise in climate science. Multiple studies have consistently shown that a strong consensus exists among scientists with specific expertise in climate science, who agree that climate change is real, human-caused, a serious problem, and that we can and should take action to mitigate the negative consequences.

Ordinary scientific debates as to the details of climate change mechanisms and timings do not invalidate in any way the fundamental observations of the reality of climate change and of the human contributions to it. These dialogues, whether in written or oral form, are a fundamental part of how science advances and self-corrects. Dialogue is the result of healthy skepticism, and through the consensus produced by scientific dialogues, the best representation of the nature of the real world emerges. As a result, calls for pedagogy focused on “teaching the controversy” in a science class are without scientific merit and should be excluded from the science classroom. There is no scientific “controversy” about current climate change that is unique or substantially different than the continual research and refinement that is an inherent part of all scientific endeavors.

Science educators need to focus on presenting concepts, including climate change, that are supported by empirically-based evidence collected from the natural world. The existence of uncertainty does not undermine the scientific validity of climate change science: To the contrary, it provides a sound example for broader instruction of science practices. The empirical evidence that science provides and the way that science both explains past events and offers possible future outcomes have roles in many academic disciplines including social studies, history, mathematics, economics, and literature classes. Science educators can and should engage teachers of these other disciplines at all grade levels to prepare students who will face critical geoscience issues such as generating sufficient clean energy, building climate resilience for businesses and communities, maintaining supplies of food and clean water, and solving the problems of global environmental change that confront society today and in its future.

2. Controversy and Personal Beliefs

One of the central components of the Science and Engineering Practices (SEPs) in both the *Framework* and *NGSS* is the expectation that students should argue from evidence. Specifically, Appendix F of the *NGSS* states that “Argumentation is a process for reaching agreements about explanations and design solutions.” This requires individuals to distinguish between opinions and evidence and be prepared to “respectfully provide and receive critiques” about evidence and scientific reasoning. This, of course, necessitates a functional dialogue among parties in the discussion. "Civil dialogue" is a form of discourse that is emphasized by the *Common Core State*

Standards for English Language Arts & Literacy in History/Social Studies, Science, and Technical Subjects. These standards include specific references for setting up, participating in, and conducting collegial discussions (NGAC and CCSSO 2010).

However, teachers who face or fear challenges from students, parents, or community members about teaching climate change in the classroom need support beyond content knowledge. Teachers should receive professional development on how to acknowledge the beliefs of students and parents while clarifying the difference between beliefs and evidence-based understandings. Teachers also need tools and strategies for dealing with socially or politically motivated controversies. These could include teaching strategies to help students analyze non-scientific aspects of controversial topics, non-biased frameworks to help students assess the credibility of sources, programs to build community and administrative support, and efforts to build social and emotional support within the teaching community. Good science teaching includes teaching students how to distinguish between non-peer-reviewed opinions and peer-reviewed scientific evidence through collaboration with social studies and language arts teachers. Cognitive biases are systematic patterns of deviation from rational thinking. In other words, they are predictable ways in which nearly everyone fools themselves into accepting things that are demonstrably false. Teaching that attends to distinguishing reliable evidence from problematic claims and that helps students recognize common weaknesses in arguments—such as logical fallacies, and cognitive biases held by students, parents, and policymakers—will help learners and teachers broadly, not merely with regard to climate change.

There have been widely-publicized calls from non-scientists to use constitutionally-guaranteed free speech and the tradition of academic freedom as a reason to “teach the controversy” and “let the students decide” based on rhetorical arguments. These are political and academic philosophies and are not equivalent to scientific philosophy of argumentation and dialogue based on empirical evidence. While these political and academic philosophies support the rights of scientists to openly discuss and publish their work, free speech and academic freedom were never intended to be the basis for the promulgations of falsehoods lacking rigorous review and solid consensus. The employment of “free speech” and “academic freedom” lacking data and empirical analysis is an abuse of the terminology to support a particular non-scientific political or economic endpoint.

A central challenge for teachers of adolescents is to provide them with the habits of mind to critically review information they receive from non-school sources. Students of this age are in the process of not only learning more complex academic information, but also defining who they are as individuals. During this process, students learn to accept or challenge information and need the tools and strategies to reconcile that acceptance or challenge with how they see themselves. A simple tool defined by Greg Craven (Craven 2009) is the credibility spectrum. This tool helps students rank-order sources of information on the basis of the natural biases of the sources compared to their relative risk of being incorrect. For example, a professional organization that provides a position statement that contradicts students' normal biases has the most to risk by being wrong and should be assigned the highest credibility. In a similar fashion, experts in a particular field of research should be assumed to "know what they are talking about," compared to scientists who venture into unrelated fields of inquiry. If students' natural inclination to challenge authority can be focused on critically evaluating sources of information based on Craven's general framework, they have taken a first step in "inoculating" themselves against information that has less scientific support (Cook et al. 2017).

Another tool for addressing alternative, and perhaps non-scientific, viewpoints relates to the nature of dialogue, which is essential for creating and evaluating scientific claims. To understand opposing points of view, it is important to identify a person's threshold for changing position. Rather than attempting to change a person's position with evidence, the key is to challenge them to define the level of evidence they need to change their mind or position. The result is that the dialogue focuses on the quantity and quality of evidence used to support a position, rather than focusing on who is "right" and who is "wrong."

Providing evidence-based arguments is essential to the development of climate literacy, but evidence alone is often insufficient and may produce a "backfire effect" that deepens commitment to unscientific beliefs (Cook and Lewandowsky, 2011). Advocacy may deepen convictions more than understandings. Often, for polarizing issues, advocacy messages may increase polarization as individuals at both poles dig in their heels. Developing and maintaining effective methods of dialogue are critical to promoting the acceptance of scientific ideas that challenge students pre-developed biases.

3. The Nature of Deep-Seated Beliefs

"The first principle is that you must not fool yourself and you are the easiest person to fool."
Quote by Richard P. Feynman, Nobel Laureate in Physics

A significant barrier to teaching climate change science resides in the cognitive biases that all individuals possess. It's important to recognize that much of individuals' cognition is based on the protection of identity, the maintenance of the status quo, and the trap that logical fallacies represent. There are psychological obstacles to the perceptions of things that do not happen, as well as the avoided consequences of those things that did not take place or have yet to take place.

The importance of scale

Some of the psychological obstacles related to understanding climate change science are the result of temporal and spatial scales. Individuals carry a personal bias to view natural events within the span of a human lifetime, so understanding the temporal scales of past changes are difficult. Earth's climate systems over the past 12,000 years have been stable enough to allow for the rise of agriculture and civilization, but even so, fluctuations in climate over this period have often caused the collapse of these same civilizations and the death of large percentages of human populations. It is easy for people to dismiss the changes in global temperature over their lifetimes (about a 1° C increase) as small compared to the changes in temperature that have occurred in the past, which have included cold Ice Ages and warm periods in the Cretaceous when all ice caps were melted. However, it is important for people to realize that the *rate of change* of many climate-related earth systems is now greater than it has ever been, and that in a small number of lifetimes the earth may change in ways that used to take thousands to millions of years to occur.

Spatial scale perception is another barrier. "Social math" uses familiar examples to show mass, volume, or relative number (NCIPC 2008). Individuals can perceive the square-footage of a house, the average volume of a tank of gas in a car, or the size of a science class, but the amount of annual human carbon emissions, presented in megatons, is more difficult. A gallon of gasoline weighs about six pounds. Burning it yields about 19 pounds of carbon dioxide, as carbon atoms in the gasoline combine with oxygen from the atmosphere to make carbon dioxide. At standard temperature and pressure, 19 pounds of carbon dioxide gas has a volume of about 1100 gallons. In the U.S., we burn about 400 million gallons of gasoline per day—more than a gallon per person per day (USEIA 2018). Visualizing the average person's carbon dioxide emissions with gallon-sized balloons can help make the scale of the issue more concrete. Understanding scale is both challenging and fundamentally important in understanding many issues related to climate and energy.

Emotions and beliefs

Learning about climate change can be a more emotional experience than learning about other scientific topics, which is an indicator of climate change's interdisciplinary nature. Climate change is an emotional topic because it is connected to issues of ideology and political identity. Anger is one conspicuous emotion related to climate issues, due in part to social media and other outreach avenues, but other emotions are also relevant. When a student's family, religious community, or political affinity are put at odds with the scientific consensus about climate change, a range of emotions can come into play. Teaching ideas at odds with the beliefs of students' families and communities can bring sadness, confusion, anger, and curiosity. These reactions do not mean that the content should be avoided, but rather it should be approached with sensitivity to these potential conflicts.

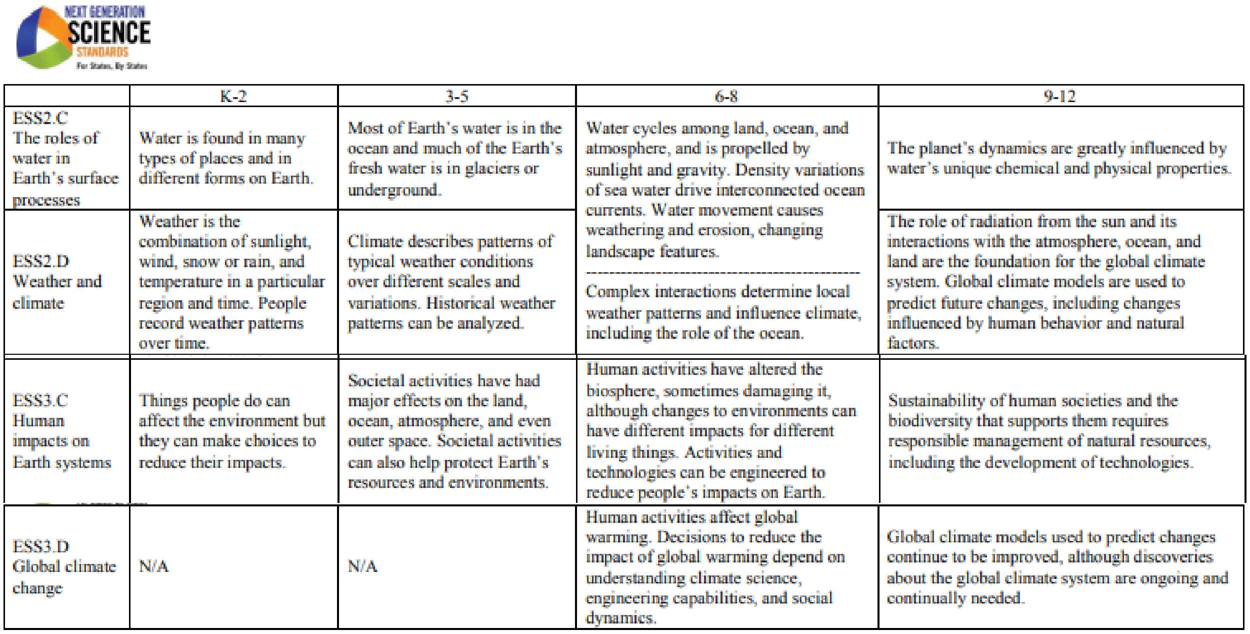
Personal versus societal beliefs

Belief systems do not necessarily arise from logic and evidence, which are the bases of scientific understanding. Belief systems are founded in one's faith, family, and personal emotional experiences unique to the individual. An individual's desire to be a part of a specific community or group will inform their beliefs and affect their ability to change based on the pressures, real or perceived, applied by the community or group in question. Because an individual's belief system is more connected to their emotions, beliefs may more likely change when analogies or stories are used. In contrast, societal beliefs are often the result of "groupthink," a phenomenon that results from the momentum of a group's mission, vision, and emotional inertia. At its most extreme, groupthink can result in a mob mentality. Politicians are often subject to groupthink as a result of the isolation and internal machinations of political establishments. Neotribalism is the result of modern groups of regular citizens who develop groupthink by engaging with all the same types of social and traditional media messaging. Avoiding groupthink and being attentive to the emotional issues connected to teaching controversial issues are essential if we are to avoid reproducing the current state of dysfunctional public discourse. Identifying communicators who come from a range of religious and political communities can enhance the likelihood of ideas being accepted. For example, climatologist Katharine Hayhoe is an evangelical Christian; former congressman Bob Inglis is a conservative Republican; and Jerry Taylor was a senior fellow at the Cato Institute who previously espoused skepticism about climate change. Encouraged to more closely review the science, Taylor eventually left the Cato Institute to advocate for climate change policies.

Relevant online resources:
www.psychologytoday.com/blog/good-thinking/201602/how-get-people-change-their-minds
www.newyorker.com/magazine/2017/02/27/why-facts-dont-change-our-minds
www.wired.co.uk/article/changing-political-beliefs
https://yourlogicalfallacyis.com/

4. The Time Needed for Learning

To understand climate change, it is necessary to first understand climate and how it is different from weather. For all children, this means that teachers are implementing age-appropriate 3-dimensional instruction that incorporates the Disciplinary Core Ideas (*NGSS* Appendix E), Science and Engineering Practices (*NGSS* Appendix F) and Crosscutting Concepts (*NGSS* Appendix G). The chart below shows the suggested *NGSS* DCI progressions for the teaching of weather, climate, and climate change. It is important to note that students start to address weather and climate in the earliest grades and continue throughout their time in school.



	K-2	3-5	6-8	9-12
ESS2.C The roles of water in Earth's surface processes	Water is found in many types of places and in different forms on Earth.	Most of Earth's water is in the ocean and much of the Earth's fresh water is in glaciers or underground.	Water cycles among land, ocean, and atmosphere, and is propelled by sunlight and gravity. Density variations of sea water drive interconnected ocean currents. Water movement causes weathering and erosion, changing landscape features.	The planet's dynamics are greatly influenced by water's unique chemical and physical properties.
ESS2.D Weather and climate	Weather is the combination of sunlight, wind, snow or rain, and temperature in a particular region and time. People record weather patterns over time.	Climate describes patterns of typical weather conditions over different scales and variations. Historical weather patterns can be analyzed.	Complex interactions determine local weather patterns and influence climate, including the role of the ocean.	The role of radiation from the sun and its interactions with the atmosphere, ocean, and land are the foundation for the global climate system. Global climate models are used to predict future changes, including changes influenced by human behavior and natural factors.
ESS3.C Human impacts on Earth systems	Things people do can affect the environment but they can make choices to reduce their impacts.	Societal activities have had major effects on the land, ocean, atmosphere, and even outer space. Societal activities can also help protect Earth's resources and environments.	Human activities have altered the biosphere, sometimes damaging it, although changes to environments can have different impacts for different living things. Activities and technologies can be engineered to reduce people's impacts on Earth.	Sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources, including the development of technologies.
ESS3.D Global climate change	N/A	N/A	Human activities affect global warming. Decisions to reduce the impact of global warming depend on understanding climate science, engineering capabilities, and social dynamics.	Global climate models used to predict changes continue to be improved, although discoveries about the global climate system are ongoing and continually needed.

Early elementary students can make observations and measurements of the more concrete aspects of weather (year-long measurements of temperatures and precipitation patterns and types of clouds) and seasons (timing of bud bursts, green-up and brown-down, migration, and blooming), create simple models of the water cycle in their local setting, define human impacts on the environment, and find ways to reduce those impacts. Older elementary students can compare weather observations with regional patterns and trends over time and identify how long-term trends of weather patterns may be changing. Students at this level can also identify examples of human impacts and those solutions that have already been enacted. Middle school students begin to connect the physical and chemical characteristics of water to atmospheric, oceanographic, biologic, and geologic processes. At this level, students are able to evaluate paleoclimates to understand how anthropogenic climate change is different from past climate change and how humans are changing the rates and functions of Earth and environmental processes. Finally, high school students use modeling, mathematics, experimentation, and analysis of large data sets to better understand complex interrelationships of Earth's atmospheric, oceanic, geologic, and biologic systems. They can design solutions to problems that result from an expanding, consumptive human population.

At each of these levels, teachers should take into consideration the audience, scaffolding of instruction, progression from concrete to abstract thinking, and social-emotional maturity. Teachers should give students opportunities to break the science down so that it is encountered in digestible chunks, culminating in the students connecting science and engineering. This process takes time, but it respects the research on learning and thinking (Kang 2016). Instead of teaching climate science and climate change all at once, teachers should work across grade bands to incrementally build upon students' understanding, revisit the science to ensure long-term retention, and enable increased complexity of thinking. This approach increases the amount of time spent on climate change and the number of times it is addressed. Aspects of climate and climate change science end up being taught in all science content areas (atmospheric/ocean chemistry, atmospheric physics, planetary orbital dynamics, and impacts on biologic systems). Furthermore, the societal, political, and cultural aspects of climate change should be addressed in humanities courses (See Common Core State Standards for ELA, science and technical subjects [CCSSO 2010(b)] and National Curriculum Standards for Social Studies, themes 3, 8, and 9 [NCSS 2010]). This incremental building of understanding complex systems is a key conceptual shift in both the *Framework* and the *NGSS*. Students build foundational understandings of the things we can see in order to predict and make sense of those things we cannot see.

By building student understanding over the full twelve years in multiple interdisciplinary courses, students have an opportunity to develop an understanding of the complexity of most modern science research and how that science is contextualized within social and psychological issues. Climate is an ideal interdisciplinary theme for lifelong learning about the scientific process and the ways in which humans affect and are affected by Earth's complex systems. This rich topic can be approached at many levels, from comparing the daily weather with long-term records to exploring abstract representations of climate within computer models, to examining how climate change impacts both human and ecosystem health (USGCRP 2009; Updated Draft 2017):

> *"In the coming decades, scientists expect climate change to have an increasing impact on human and natural systems. In a warmer world, accessibility to food, water, raw materials, and energy are likely to change. Human health, biodiversity, economic stability, and national security are also expected to be affected by climate change. Climate model projections suggest that negative effects of climate change to humans will significantly outweigh positive ones. The nation's ability to prepare for and adapt to new conditions may be exceeded as the rate of climate change increases."* (Climate Literacy, Informed Climate Decisions Require an Integrated Approach, 2009)

It is important that climate change instruction emphasize the positive technological opportunities that exist to minimize the impacts that human activities are having on climate systems. It is more productive to help students address climate change challenges using engineering design methods rather than by focusing on the evils that society has committed. For example, *NGSS* performance expectations that address climate change are often coupled with engineering and technology concepts and require students to use the engineering design process to construct, evaluate, and revise solutions to human impacts. These performance expectations encourage students to examine and evaluate engineered solutions on both small and large spatial scales.

Teaching about any form of human impact on Earth systems is most effective when students are encouraged to explore mitigation and adaptation strategies and solutions to problems, and not focus solely on the problem (Niepold 2017). The challenges of global warming are complex and cannot easily be fixed using known strategies. Students should be encouraged to think creatively and devise solutions using skills and knowledge of science, mathematics, technology, and engineering. Teachers should guide students to focus solutions on mitigating and reducing human-produced greenhouse gases and give them the freedom to explore the sequestration, active removal, or amelioration of these pollutants once they are in the environment. Given the need for accelerated action, no solution should be "off the table." Students should have the opportunity to evaluate all possible and proposed solutions, considering and analyzing these for effectiveness, cost, and potential unforeseen consequences.

In the process of seeking solutions, students are asked to do something that is not being done by many adults. Students need access to an active STEM research and development climate solutions community. At the local level, this access could be in the form of high school internships and summer research opportunities, developing on-the-ground education and outreach through power supply companies and water management organizations, and orchestrating school-community partnerships that bring students and organizations together in meaningful ways. At a national scale, this could include work already being done by the National Renewable Energy Laboratories, California Climate Change, and the Center for Climate and Energy Solutions, to name a few. Furthermore, by emphasizing the real and important impacts of local solutions, teachers motivate and inspire students to do those things that sometimes overwhelm adults.

Globally, we face generations of atmospheric and oceanic warming. This idea may be overwhelming, but there is no time to waste in the development of strategies for the reduction and amelioration of human impacts. We need a well-informed and educated population capable of

- teaching the complexities of climate change, its impacts, and mitigation and adaptation strategies at all grade levels;
- identifying sources of and practicing widespread mitigation of greenhouse gases; and
- researching and developing mitigation solutions to the challenges presented by climate change.

One of the most effective strategies is to teach climate change science at every grade level by implementing 3-dimensional instruction in STEM courses, addressing the systematic cultural and social factors that resist behavioral changes, and providing communities with strategies to engage people across generations to work together to find solutions for their regions.

5. Responses to Climate Change

Human activity has changed the chemistry of the atmosphere in ways that are altering atmospheric dynamics and changing global and regional climates. While climate has changed markedly throughout the 4.5 billion years of Earth's history, it has been comparatively stable for the past 10,000 years. This relative stability has allowed human agriculture and civilizations to rise and flourish, supporting the nearly exponential growth of the human population. The rise of civilizations, the alteration of atmospheric chemistry, and the changes of climate intertwine. Indeed, the potential effects of increased greenhouse gases in the atmosphere, most notably from carbon dioxide, have been recognized since the work of John Tyndall in 1859 (Hulme 2009).

Carbon-dense fossil fuels brought about the Industrial Revolution and ultimately made our modern way of life possible. The continued extensive use of these same fuels now jeopardizes that very way of life for current and future populations around the world. The teaching of climate change science should enable learners to strategize solutions to human energy needs, examining multiple costs and benefits. While there are environmental and economic costs to all forms of energy production, students need to be able to analyze and argue for energy production strategies that are most cost effective for the natural and human environment. Social and individual decision making will drive the deployment of lower impact technologies and of new technologies based on continual scientific discoveries, which will in turn reduce the costs and risks, allowing human societies to sustainably develop. It is current students who will be continuing to make these decisions in their future.

> *"Reducing our vulnerability to these impacts depends not only upon our ability to understand climate science and the implications of climate change, but also upon our ability to integrate and use that knowledge effectively. Changes in our economy and infrastructure as well as individual attitudes, societal values, and government policies will be required to alter the current trajectory of climate's impact on human lives. The resolve [and capacity] of individuals, communities, and countries to identify and implement effective management strategies for critical institutional and natural resources will be necessary to ensure the stability of both human and natural systems as temperatures rise."* (Climate Literacy, Informed Climate Decisions Require an Integrated Approach, 2009).

There are useful historic examples of how large-scale governmental actions have reversed trends in harmful human-induced impacts. The near-global ban on the release of chlorofluorocarbons into the atmosphere stopped the growth of the Antarctic ozone hole, and the U.S. environmental legislations in the early 1970's reversed pollution trends for air and water. Reducing human-caused pollution allowed the Earth systems to begin to repair themselves. For example, the Antarctic ozone hole is no longer enlarging and has recently shown signs of shrinking. In both of these cases, the Earth systems can repair themselves relatively quickly (decades to centuries) because of the fast overturn times of atmospheric and surface water-cycle time scales, at weeks to years.

However, it would be a mistake to present the current climate change trends as something that could be easily fixed through forms of geoengineering or climate intervention. Global climate change is a much larger and more complex problem because of the long overturn time of the ocean, which is on the order of thousands of years. The heat and carbon dioxide that are currently being pumped into the ocean will remain there for thousands of years and then gradually return to the surface as the ocean continues to circulate. While the best solution to global warming is, like these other examples, halting the release of pollutants (in this case, greenhouse gases), students at all levels need to recognize that there are no quick fixes to this problem, and that even with the immediate cessation of industrial-borne carbon dioxide, global temperatures will still continue to rise for many centuries.

Climate research has shown that once carbon dioxide is in both the atmosphere and ocean at the enormous quantities now existing, removing it or countering its effects will require climate intervention actions at unrealistically enormous scales, and these actions would not only be exorbitantly expensive, but would create unintended environmental impact problems. Research has shown, for example, that seeding the ocean with vast amounts of metal would indeed reduce the amount of carbon dioxide but would produce extreme negative impacts both from the amount of mining required and from the vast algal blooms that would result. Research has also shown that ejecting enormous quantities of aerosols into the atmosphere would indeed slow the rate of global warming by reducing the sun’s incoming radiation, but that these aerosols would also reduce precipitation rates, worsening droughts in many parts of the world. While it is critical that students examine all options available for reducing global warming, it is also important that they do so in the context of humans’ new role as the largest agent of geologic change on the planet and the awareness that anything humans now do on a global scale will have enormous impacts on the planet.

Human impacts to climate change can be seen as a result of human population, both in relative size and growth rate. There would not be the same discussion of climate change at all if human populations were still at the levels they were even just a few centuries ago, a remarkably small amount of time on geologic scales or even the scale of the 300,000 years of the existence of homo sapiens. However, with 7.5 billion humans on the planet, the collective result of individual human actions creates enormous planetary impacts. We humans now control more than 50% of continental surface area, using more than 40% of it to feed ourselves (crops and grazing lands). Globally, human-caused erosion rates are 6 times the erosion rates from all natural causes combined. These numbers are also rapidly increasing as human populations increase. The human population was 2 billion in 1927. It has almost quadrupled in one lifetime and is adding another billion people every 15 years. Human population is also a controversial and emotionally charged subject with its own unique set of political and religious biases, but human consumption of energy resources is what is driving the current warming of global temperatures, and in this context, the numbers of humans on Earth as well as our habits of consumption and patterns of development are part of the *NGSS* performance expectations (e.g., PE HS-ESS3-3) and must be included in discussions of climate and climate change.

Climate change science offers an opportunity to learn from projections of different carbon emission pathways and their various climate impacts before we experience them, while also providing insights into how we can avoid those impacts. Taken together, scientific understanding of the causes and potential consequences of climate change provide a clear imperative for a rapid transition to a low-carbon economy. However, to close the emissions gap, we must also close the education gap, transferring knowledge from science to society so that we can build the necessary political will, scaled solutions, and effective innovations and make informed emissions decisions over the next several decades. Even if we are successful in achieving enough climate change mitigation, education must also play a vital role in helping citizens adapt by building their knowledge and skills and changing behaviors in ways that enable society to reduce its vulnerability to impacts that are now inevitable. It is likely that the rate of change in technologies related to energy and transportation in the coming 40 years will be at least as great as the last 40 years. If due attention is paid to using less energy and to continue the fast pace of cleaner energy innovations, there is reason for optimism. Of course, quick substantial attention will be more likely to succeed than delayed small-scale innovation. Education is critical in enabling informed decision-making based on projections of potential impacts, rather than relying on experience that will come too late.

References

Cook, J., and S. Lewandowsky. 2011. *The Debunking Handbook*. St. Lucia, Australia: Global Change Institute, University of Queensland.

Cook, J., S. Lewandowsky, and U. K. H. Ecker. 2017. Neutralizing misinformation through inoculation: Exposing misleading argumentation techniques reduces their influence. *PLOS ONE* 12, no. 5 (May 5, 2017).

Craven, G. 2009. *What's the worst that could happen?: A rational response to the climate change debate*. 1st ed. New York: Perigee.

Hulme, M. 2009. On the origin of 'the greenhouse effect': John Tyndall's 1859 interrogation of nature. RMETS (Royal Meteorological Society).

Kang, S. H. K. 2016. *Spaced Repetition Promotes Efficient and Effective Learning: Policy Implications for Instruction*. Policy Insights from the Behavioral and Brain Sciences. Vol. 3(1) 12–19.

National Center for Injury Prevention and Control (NCIPC). 2008. *Adding Power to Our Voices: A Framing Guide for Communicating About Injury.* Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention; 2008 (revised March 2010).

National Council for the Social Studies (NCSS). 2010. *National curriculum standards for social studies: A framework for teaching, learning, and assessment*. Executive Summary. Silver Spring, MD: NCSS.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010(a). *Common core state standards*. Pages 48-50. Washington, DC: NGAC and CCSSO.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010(b). *Common core state standards.* English Language Arts Standards. Washington, DC: NGAC and CCSSO.

National Research Council (NRC). 2012. *A Framework for K–12 Science Education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

National Science Teachers Association (NSTA). 2018. NSTA Position Statement: The Teaching of Climate Science.

Niepold, F. 2017. Education Ensures Strong, Sustained, and Effective Climate Solutions. Green Schools National Network. April 18, 2017.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

U. S. Energy Information Administration (USEIA). 2018. U.S. Product Supplied of Finished Motor Gasoline (Thousand Barrels per Day). Accessed September 11, 2018.

U.S. Global Change Research Program (USGCRP). 2009. *Climate Literacy: The essential principles of climate science*. Washington, DC: U.S. Global Change Research Program.

U.S. Global Change Research Program (USGCRP). 2017. *Climate Science Special Report: Fourth National Climate Assessment, Vol. 1* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. Washington, DC: U.S. Global Change Research Program.