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NEWS & ANALYSIS

Toward a Climate-Literate Society

by Mark S. McCaffrey and Susan M. Buhr

In 1958, as part of the science education efforts for the International Geophysical Year, a National Academy of Sciences (NAS) publication, *Planet Earth: Mystery With 100,000 Clues*, explained that the natural greenhouse effect was being altered. "[O]ur industrial civilization has been pouring carbon dioxide into the atmosphere at a great rate," and if this continued, "it would have a marked warming effect on the earth's climate" and could "cause significant melting of the great ice caps and raise sea levels in time."[1] Despite the 50-year lead time afforded by this portent of our current circumstances, citizens today hold significant and pervasive misunderstandings about climate science.[2] Students and even teachers in modern classrooms exhibit multiple misconceptions about the climate system in general, and the causes and effects of climate change in particular.[3]

While many efforts have focused on promoting a change of behavior aimed at reducing greenhouse gas (GHG) emissions, "an educated citizenry is required to make wise decisions regarding policies and practices aimed at reducing greenhouse gas emissions and the human impact on the Earth's resources."[4] To support wise decisionmaking, an understanding of basic climate processes is imperative. In their paper, *The Case for Climate Literacy in the 21st Century*, Frank Niepold and colleagues call for a large climate literacy effort in the United States that "enables and fosters numerous partnerships, alliances and collaborations across the entire spectrum of educators, communicators, and science centers to achieve wider and more efficient opportunities to engage the public."[5] They go on to state that "our country's future depends on the abilities of the public to plan proactively for the complexities of the 21st century."[6]

What is climate literacy? What are some of the challenges and impediments in fostering climate literacy through formal and informal education? Will improved societal understanding of climate help prepare communities for natural hazards, such as drought and coastal storms, or assist in achieving reduced emissions? The answers to these questions are not simple, as the causes and effects of human decisions and actions on climate, like the climate system itself, are complex and often nonlinear.

As discussed in Susanne Moser and Lisa Dilling's *Creating a Climate for Change*, we cannot presume that information and knowledge will necessarily lead directly to right action. The deficit model, whereby people are presumed to make informed decisions once their cognitive deficiencies and gaps have been filled, is not well supported by social science theory and empirical research. Authors Caron Chess and Branden Johnson note that "more knowledge does not necessarily lead to more appropriate behavior" and that "information is not entirely inconsequential, but it is much overrated as a change agent."[7] However, Richard Bord and colleagues found that "knowing what causes climate change, and what does not, is the most powerful predictor of both stated intention to take voluntary actions and to vote on hypothetical referenda to enact new government policies to reduce greenhouse emissions."[8] In order to understand the causes of anthropogenic climate change, it is crucial to understand the basics of the climate system to avoid confusion and misconceptions.

I. Development of the Climate Literacy Framework

To improve climate communications between research scientists and educational practitioners, a broad community of researchers, educators, and colleagues from multiple disci-

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1. NAS, Planet Earth: Mystery With 100,000 Clues (1958), *available at* http://www7.nationalacademies.org/archives/IGYPlanetEarthPosters.html. The educational booklet, posters, and films, particularly one entitled "The Inconstant Air," are important science education artifacts. They also demonstrate how robust the scientific understanding of climate processes and the earth system were 50 years ago. The films are available on the Internet at http://lasp.colorado.edu/igy_nas/.
2. ABC News/Planet Green/Stanford Poll, *Fuel Costs Boost Conservation Efforts; 7 in 10 Reducing "Carbon Footprint,"* Aug. 9, 2008, http://abcnews.go.com/images/PollingUnit/1067a1Environment2008.pdf (last visited Oct. 17, 2008).
3. Catherine Gautier et al., *Misconceptions About the Greenhouse Effect*, 54 J. Geoscience Educ. 386 (2006), *available at* http://www.nagt.org/files/nagt/jge/abstracts/gautierv54p386.pdf.
4. Todd Cordero et al., *Climate Change Education and the Ecological Footprint*, 89 Bull. Am. Soc'y 865, 872 (2008).
5. Frank Niepold et al., The Case for Climate Literacy in the 21st Century 1-11, Fifth International Symposium on Digital Earth (June 5, 2007).
6. *Id*.
7. Caron Chess & Branden B. Johnson, *Information Is Not Enough*, *in* Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change 223 (Susanne Moser & Lisa Dilling eds., 2007).
8. Richard Bord et al., *In What Sense Does the Public Need to Understand Global Climate Change?* 9 Pub. Understanding Sci. 205 (2000).

plines built on prior efforts to develop a comprehensive, research-based framework for climate literacy through an iterative peer-review process.

Inspired by the work of the ocean science education community who developed and published a broad-based framework for Ocean Literacy in 2005,[9] the National Oceanic and Atmospheric Administration (NOAA) funded a workshop entitled "A Framework for Weather and Climate Literacy." It was held in April 2007, and was co-hosted by NOAA and the American Association for the Advancement of Science (AAAS) Project 2061 (Project 2061).[10] The workshop, attended by over 20 participants, approximately one-half from NOAA, reviewed the ocean literacy framework and other materials developed by Project 2061.[11] Because many of the participants were unfamiliar with Project 2061 and the Benchmarks for Science Literacy, the initial discussion focused on the research that had gone into developing the conceptual strand maps. The strand maps, which are organized by grade level, link to other maps and are built on learning goals and research on cognitive development.[12] One of the common misconceptions that tripped up Harvard graduates in the "Private Universe" study[13]—how the tilt of earth on its axis is the "reason for the seasons"—is often taught (or attempted) in middle and even elementary school. However, Project 2061 researchers learned that students are not sufficiently versed in the geometry and physics of the earth system to understand this concept until high school.[14]

The workshop had several primary outcomes: a draft framework of essential principles and fundamental concepts; a call to establish a climate literacy coalition outside of the federal agencies (which has resulted in the Climate Literacy Network)[15]; and an iterative process of incorporating feedback solicited online and through a related workshop.[16] After thorough community vetting, the Essential Principles of Climate Literacy framework was released in spring 2008 at the National Science Teachers Association meeting, and is now available online through the Climate Literacy Network[17] and the NOAA Climate Office.[18] The topics covered by the seven essential principles are: (1) life and climate are interdependent; (2) observations and computer modeling contribute to climate science; (3) climate is driven by energy from the sun; (4) complex interactions control the climate system; (5) climate experiences natural variability and change; (6) human activities change climate; and (7) human decisions influence Earth's climate system.

II. The Essential Principles of Climate Literacy in Formal Education

Building a climate-literate society through education is no small task. Several notable efforts have provided educational background information on climate processes and anthropogenic climate, such as the U.S. Environmental Protection Agency's (EPA's) Global Warming for Kids website,[19] the National Aeronautics and Space Administration (NASA)-funded Global Warming Project,[20] and NOAA's Paleo Perspectives on Global Warming,[21] Abrupt Climate Change,[22] and Climate TimeLine.[23] But, professional development in climate science has not been widespread for pre-service and practicing teachers. Additionally, standards have not required that climate science be taught in most states, and learning resources vary widely in quality.[24]

9. Ocean Literacy Network, *Homepage*, http://www.coexploration.org/oceanliteracy/ (last visited Oct. 6, 2008).

10. Susan Lynds et al., Framework for Climate and Weather Education Workshop Summary Report (2007). *See also* Frank Niepold, Update: Framework for Climate and Weather Literacy Workshop and Next Steps (2007), *available at* http://environment.yale.edu/climate/2007/07/05/update-framework-for-climate-weather-literacy-workshop-next-steps/.

11. Materials included the recently released *Atlas of Science Literacy*, *see* 2 AAAS, Atlas of Science Literacy (2007), which includes Strand Maps on Weather and Climate, and the booklet from AAAS, *Communicating and Learning About Global Climate Change*, *see* Project 2061, AAAS, Communicating and Learning About Global Climate Change: An Abbreviated Guide for Teaching Climate Change (2007), *available at* http://www.Aaas.Org/news/press_room/climate_change/mtg_200702/climate_change_guide_2061.pdf (last visited Oct. 6, 2008).

12. "To produce thoughtful maps, a set of learning goals also has to be complete and coherent enough to provide a suitable framework—all the conceptually important ideas or skills need to be there in the first place." Atlas of Science Literacy, *supra* note 11, at 122. Many of the AAAS Strand Maps, including Weather and Climate, are available on the Internet, *see* National Science Digital Library, *Strand Maps*, http://strandmaps.nsdl.org/?id=SMS-MAP-9030.

13. DVD: A Private Universe (Harvard-Smithsonian Center for Astrophysics 1987), *available at* http://www.learner.org/resources/series28.html (last visited Oct. 9, 2008).

14. It is unfortunate that few students, when they are cognitively ready to appreciate why somewhat complex concepts, such as the tilt of the earth on its axis, are actually given opportunities to learn such content since it often falls outside the disciplinary realm of traditional high school science.

15. Climate Literacy Network, *Homepage*, http://www.climateliteracynow.org (last visited Oct. 8, 2008).

16. The follow-up workshop, funded by the National Science foundation with the involvement of NOAA, was co-hosted by the University Corporation for Atmospheric Research and the Cooperative Institute for Research in Environmental Sciences. Held in Boulder, Colorado, from Nov. 27-29, 2007, the workshop focused on Atmospheric Science and Climate Literacy, but because the Climate Literacy work was well underway, having been through some 20 iterations incorporating the input for dozens of experts, the workshop and subsequent draft "Essential Principles" focused on atmospheric processes, which overlap and complement climate processes, but are in effect different slices of the earth system and spheres. For more on the Atmospheric Science Literacy Framework Workshop, see http://www.eo.ucar.edu/asl/ (last visited Oct. 8, 2008).

17. *See supra* note 15.

18. NOAA, *Climate Literacy: The Essential Principles of Climate Science*, http://www.climate.noaa.gov/education/pdfs/climate_literacy_poster-final.pdf (last visited Oct. 8, 2008).

19. U.S. EPA, *Global Warming for Kids*, http://epa.gov/climatechange/kids/. EPA also developed a toolkit on climate change, wildlife, and wildlands. U.S. EPA, *Climate Change, Wildlife, and Wildlands Toolkit*, http://www.epa.gov/climatechange/wycd/ORWKit.html.

20. The Global Warming Project was developed at Northwestern University through a grant from NASA. Northwestern University, *Welcome to the Global Warming Project*, http://www.letus.northwestern.edu/projects/gw/ (last visited Oct. 8, 2008).

21. NOAA, *Paleo Perspective on Global Warming*, http://www.ncdc.noaa.gov/paleo/globalwarming/home.html (last visited Oct. 9, 2008).

22. NOAA, *Paleo Perspective on Abrupt Climate Change*, http://www.ncdc.noaa.gov/paleo/abrupt/index.html (last visited Oct. 9, 2008).

23. NOAA, *Climate TimeLine Information Tool*, http://www.ncdc.noaa.gov/paleo/ctl/ (last visited Oct. 9, 2008).

24. One of the techniques used in classrooms has been to hold a debate between teams of students as to whether human activities are creating global warming or not. While such a debate may encourage students to role play various perspectives and develop their own research to buttress their positions, it also perpetuates the mistaken notion held by many in the United States that there is still wide disagreement among scientists about human impacts on the climate

The Essential Principles of Climate Literacy provides an authoritative set of principles and concepts, which constitute a basic understanding of climate science. This framework is meant to provide a foundation on which instruction, curriculum, and professional development may be built. Through use of the Essential Principles, teachers can identify which climate science concepts are developmentally appropriate for their students and which lead to a robust understanding. Educators can see explicit alignment between climate science and the National Science Education Standards.[25] Curriculum and professional development providers may define and align their offerings within the scope of the Essential Principles.

One of the goals in developing the Essential Principles was to develop a framework that will help address misconceptions and confusion relating to climate that have been identified by research and experience. These include the reason for the seasons, the basic dynamics of the greenhouse effect and the carbon cycle, and the belief that global warming is caused by the ozone hole.[26]

These findings are consistent with other studies on science literacy, such as the National Science Foundation's *Survey of Public Attitudes Toward and Understanding of Science and Technology*,[27] which found that while interest in science is strong, 45% of adults surveyed in 2006 are confused about how long it takes the earth to orbit the sun (one year), and only 43% agree that "[h]uman beings, as we know them today, developed from earlier species of animals," which is down from 53% in 2001.[28] Consistently, these studies show that people consider themselves to be more scientifically literate than they actually are.

III. Next Steps: Current Resources and Professional Development

Endorsed by NOAA, the National Science Foundation, EPA, the U.S. Forest Service, the American Meteorological Society, the University Corporation for Atmospheric Research, the Cooperative Institute for Research in Environmental Sciences, and numerous educational institutions and organizations, the Essential Principles of Climate Literacy framework is a living document to be revisited and updated over time. Pursuant to national reform, the Essential Principles offer a foundation for instruction aimed at deep conceptual understanding, but are only the first step toward the goal of a climate-literate society.[29]

As anticipated, with the release of the framework in spring 2008, educators immediately requested high-quality web resources for their students and professional development for themselves to support the use of the Essential Principles in their classrooms. In order to implement instruction aligned with the Essential Principles of Climate Literacy, teachers need high-quality, up-to-date teaching resources and professional development. Digital resources are especially suited for climate education, as they can be updated and supplemented as new knowledge becomes available. However, to be effective, these resources must be of high scientific and pedagogical quality.

Pedagogical challenges within climate education relate to addressing core misconceptions and the complexity of the science—from the "reason for the seasons" to confusion about the differences between weather and climate, and the role of carbon in the climate system.[30] Mary Catherine Bateson also notes the need for instruction to address the "habits of thought" that stand in the way of systems thinking.[31] In the midst of these demands, few middle or high school science educators have robust backgrounds in the sciences they teach, let alone the complex, interdisciplinary realm of climate science.[32]

Textbooks and traditional teaching materials offer scant respite. Standard curriculum and textbook adoption cycles are often slow and subject to protracted state and local review and debate, leaving them disconnected from rapid breakthroughs in climate science.[33] For example, observed sea ice melt and changes in ice sheets are occurring faster than models had predicted[34] and a steady stream of reports[35] and studies[36] continually update the various reports from the Intergovernmental Panel on Climate Change. This disconnect quickly leads to outdated educational resources.

system. A more current classroom role-playing scenario could accept that "the debate is over" and focus on policy options and examining public pre-conceptions, such as are presented in the study, Jon Krosnick, *Exclusive Global Warming Poll: The Buck Stops Here*, New Scientist Env't, June 20, 1997, *available at* http://environment.newscientist.com/article.ns?id=mg19426091.500&print=true (last visited Oct. 9, 2008).

25. While many teachers are familiar with national standards, states and some school districts have their own standards that teachers are accountable to, driving much of what is taught in classrooms. A recent study conducted by Dan Barstow and colleagues at TERC (an education research and development organization) for NOAA found that in reviewing the Earth Science Standards for 50 states, the topics of climate, weather, and ocean are missing from many state standards. *NOAA Releases Nation-Wide Study of Earth Science Standards*, TERC, June 28, 2007, *available at* http://www.terc.edu/newsroom/937.html (last visited Oct. 9, 2008).

26. Gautier et al., *supra* note 3; Cordero et al., *supra* note 4.

27. National Science Foundation, *Survey of Public Attitudes Toward and Understanding of Science and Technology*, Apr. 20, 2007, http://www.nsf.gov/statistics/showsrvy.cfm?srvy_CatID=6&srvy_Seri=17 (last visited Oct. 9, 2008).

28. National Science Foundation, *Chapter 7: Science and Technology: Public Attitudes and Understanding*, Jan. 2008, http://nsf.gov/statistics/seind08/c7/c7h.htm (last visited Oct. 9, 2008).

29. *See* AAAS, Benchmarks for Science Literacy (Oxford Univ. Press 1993); Atlas of Science Literacy, *supra* note 11, at 118; Nat'l Council of Teachers of Mathematics, Principles and Standards for School Mathematics (2000); NAS, Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future 112-13 (2007); and Research Council, National Science Education Standards (National Academies Press 1996).

30. Tina Grotzer & Rebecca Lincoln, *Educating for "Intelligent Environmental Action" in an Age of Global Warming*, *in* Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change 266-80 (Susanne Moser & Lisa Dilling eds., 2007).

31. Mary Catherine Bateson, *Education for Global Responsibility*, *in* Creating a Climate for Change: Communicating Climate Change and Facilitating Social Change 287 (Susanne Moser & Lisa Dilling eds., 2007).

32. Valerie Otero et al., *Professional Development: Who Is Responsible for Preparing Science Teachers?*, 313 Science 445 (2006), *available at* http://www.sciencemag.org/cgi/content/full/313/5786/445.

33. Marcy Stein et al., *Textbook Evaluation and Adoption Practices*, 17 Reading & Writing Q. 5 (2001).

34. Julienne Stroeve et al., *Arctic Sea Ice Decline: Faster Than Forecast*, 34 Geophysics Research Letters L09501 (2007).

35. Tom Karl et al., Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands (2008).

36. Catia M. Domingues et al., *Improved Estimates of Upper-Ocean Warming and Multi-Decadal Sea-Level Rise*, 453 Nature 19, 19 (2008).

At the same time, new resources to explain basic climate concepts are becoming more sophisticated. They avoid representations that lead to misconceptions or employ visualizations and animations that explain concepts in a new way. In order to teach climate science effectively, teachers must be able to find current, authoritative resources that promote a proper scientific understanding of climate science and climate change.

Digital resources may be part of the solution to these issues. Over the past decade, teachers have increasingly sought out resources on the Internet.[37] Teachers use digital learning resources to provide just-in-time instruction, teaching topics related to current events, making use of online data, visualizations, and animations. While teachers may use popular search engines to locate learning resources, that strategy does not ensure that the returns are educationally relevant or scientifically accurate.[38] Digital library searches may be more educationally relevant than a popular search engine, but the search results may not be firmly tied to the concept of interest nor been subjected to review for accuracy.[39] To address this, "hand-selected" collections of peer-reviewed and annotated digital resources related to strategic Climate Literacy concept areas that target the middle and high school level should be developed.

Science educators describe scattered professional development in climate science education rather than comprehensive training.[40] Likewise, professional development for teachers based upon the Climate Literacy framework should develop educational expertise termed pedagogical content knowledge (PCK). This includes knowledge of where to find high-quality resources, how to identify and address misconceptions, and strategies for teaching climate science in the classroom. High PCK, or the knowledge of "how to teach" a particular topic has been shown to be critical to good instruction.[41] Professional development for teachers,[42] whether through formal workshops or online training, is required to develop robust PCK.

IV. Conclusion

Clearly, there are substantial gaps in public understanding of climate processes, human impacts on the climate system, and the degree of scientific consensus about human contributions to climate change.[43] Concepts in climate science are often difficult for students (and adults) to grasp, giving rise to misconceptions about deep time, variability over time and space, the carbon cycle, the nature of science and scientific uncertainty, nonlinear systems behavior, and the nature of models. Students and adults alike often have misconceptions rooted in information gleaned from the popular media, and may possess strong sociocultural attachments to their misconceptions or opinions.

The need for humans to have an understanding of the climate's influence on individuals and society, and society's influence on climate is imperative. Fifty years after the International Geophysical Year, human population has more than doubled, fossil fuel emissions have tripled,[44] and energy demand is forecast to increase 50% between 2005 and 2030.[45] Just as our economy is influenced by weather and climate (up to 40% of the approximately $10 trillion U.S. economy is affected by weather and climate events annually),[46] so, too, is climate influenced by socioeconomic decisions and conditions.

Ironically, the climate crisis may prove to be the ideal interdisciplinary, integrating theme for transcending traditional disciplinary boundaries in education, serving as a catalyst to synthesize arts and sciences, humanities, and social studies to benefit humanity and the environment. To be successful, climate literacy education requires immediate short-term strategies, such as high-quality, authoritative Internet resources, training, and professional development workshops. They also require long-term efforts to infuse climate literacy throughout formal and informal education, beginning with simple observations of local weather, leading to investigations of longer term, more complex processes, and moving into problem-based, service learning, and community-focused topics relating to applied and integrated climatic, ecologic, and economic research.

37. Myles Boylan, *What Have We Learned From 15 Years of Supporting the Development of Innovative Teaching Technology?*, 22 Soc. Sci. Computer Rev. 405 (2004); Yehudit Dori et al., *Characteristics of Science Teachers Who Incorporate Web-Based Teaching*, 32 Res. Sci. Educ. 511 (2002).

38. Katherine Hansen & Bethany Carlson, Effective Access: Teachers' Use of Digital Resources in STEM Teaching 16 (Gender, Diversities & Tech. Inst., Educ. Dev. Ctr, Inc. 2005).

39. Jennie C. Stephens, *Climate Science to Citizen Action: Energizing Nonformal Climate Science Education*, 89 EOS 204-05 (2008).

40. Participants in CIRES climate communications workshops have often described attendance at some talks and having seen "An Inconvenient Truth" as their climate science preparation. Todd Cordero and colleagues note previous "studies of students and pre-service teachers found that they have significant misconceptions about global warming." *See* Cordero et al., *supra* note 4.

41. *See* Justi Driel et al., *Developing Science Teachers' Pedagogical Content Knowledge*, 35 J. Res. Sci. Teaching 673 (1998); Lee S. Schulman, *Those Who Understand: Knowledge Growth in Teaching*, 15 Educ. Researcher 4 (1986); and William R. Veal & James G. MaKinster, *Pedagogical Content Knowledge Taxonomies*, 3 Elec. J. Sci. Educ. (1999), *available at* http://unr.edu/homepage/crowther/ejse/vealmak.html (last visited Oct. 9, 2008).

42. Many teachers outside the formal science disciplines of chemistry, physics, and biology, including social studies and geography educators, should be given opportunities for professional development since climate inherently crosses many disciplines and content areas.

43. *See* ABC News, *supra* note 2.

44. Woods Hole Oceanographic Institution, *Global Warming: What Is Happening and How We Can Solve It*, http://polardiscovery.whoi.edu/poles/climate.html (last visited Oct. 9, 2008).

45. Energy Info. Agency, International Energy Outlook (2008), *available at* http://www.eia.doe.gov/oiaf/ieo/index.html (last visited Oct. 9, 2008).

46. *The Impact of Weather and Climate on Society and a Vision for the Future, in* Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations (National Academies Press 2003), *available at* http://www.nap.edu/openbook.php?record_id=10658&page=22 (last visited Oct. 9, 2008).