FOSTERING INTEGRATED SCIENCE

Marty Goldhaber

The Nobel Prize–winning atmospheric chemist Paul Crutzen suggested the term "Anthropocene" for the period we live in, because of the profound impact humanity has on the planet. The more we learn about human impacts, the more appropriate that designation seems. In fact, the Stratigraphy Commission of the Geological Society of London proposed that the Anthropocene be considered a true geological epoch—one that began at about the time of the industrial revolution and in which humanity has come to dominate Earth-surface geologic processes[1]. An abbreviated list of the grounds for such a designation is disquieting:

- Humans have already transformed 40–50 percent of the ice-free land surface of the Earth.
- Humans now use 54 percent of the available fresh water on the globe.
- Humans are now an order of magnitude more important in moving sediment than the sum of all natural processes operating on the surface of the planet.
- Humans now fix more atmospheric nitrogen than all terrestrial sources combined.

Such impacts speak to the extent of our footprint on the planet. These and other planetary-scale changes are driving extensive modifications to the ecosystems that support life on Earth (see, for example, the reports of the Millennium Ecosystem Assessment, www.millenniumassessment.org/en/index.aspx). Understanding and mitigating humankind's impacts on nature and their profound feedbacks to society are what Rittel and Webber called "wicked problems."[2] They are wicked because of their complexity—they always occur in a social context with a diversity of stakeholders. These wicked problems are coming our way. They transcend the scale and scope of any one scientific discipline. Characterizing and mitigating the impacts of planetary change or adapting to them goes beyond requiring input from many disciplines (multidisciplinary science), and even beyond interdisciplinary science (i.e. a cumulative approach that synthesizes the perspectives of the individual disciplines). These wicked problems also require *integrated* science, in which issues are framed in entirely new ways that transcend discipline boundaries.

Most of us who read this magazine have research careers focused on aspects of mineralogy and geochemistry. In other words, we are engaged in disciplinary research. Though a disciplinary effort may involve many scientists and the scope of the analysis may be broad, the research still employs the methods and theories of a single discipline. Over my 35-year career, as our understanding of the planet has grown, I've observed a dramatic increase in the number of subfields comprising Earth science. Of course, this process has not been limited to Earth science—a more general fragmentation of science has taken place. For most researchers, just keeping up with the literature in our own corner of the scientific world is a real challenge. A number of other forces are driving us towards specialization, including the disciplinary nature of academic departments that grant doctoral degrees and the way research recognition and funding are organized. We certainly realize that our scientific contributions represent important but minute pieces within the enormous mosaic of human knowledge. Our disciplinary focus as scientists can take us away from thinking about integrated Earth science. But sometimes, as in viewing an impressionist painting, we need to step back to see the larger image. The reason is planetary change.

Now is a particularly important time to take in this larger perspective. Earth scientists, including those of us who work in disciplines lying outside the arena of environmental science, have a deep understanding of natural processes. Given our expertise, we have a special responsibility to contribute to the scientific and public understanding of environmental change. Jane Lubchenco considered the issue of responsibility of scientists to society in her presidential address to the American Association of Science.[3] She stressed that because the needs of society are changing rapidly and dramatically, it may require a new social contract for science, one that takes into account the human domination of the planet. "The contract should be predicated upon the assumptions that scientists will address the most urgent needs of society in proportion to their importance." She was certainly not advocating abandoning fundamental research. Indeed, she stressed that "new knowledge is urgently needed." This new contract should (and will) become an increasingly important ingredient of the scientific enterprise.

As a practicing Earth scientist, if this idea of a new contract resonates with you but your research is not directly related to the planetary change issues, what should you do? There are many things, but one that perhaps has received less attention than others is our opportunity to take ownership of the importance of, and foster, integrated science. One of the first steps is simply by staying informed. Certainly, there is an abundance of literature on the natural and social science of planetary change. A real opportunity is to participate in broad-based Earth or general science meetings. At these meetings, the number of sessions focused on aspects of planetary change is increasing rapidly and they represent an outstanding educational opportunity. For example, over 50 sessions at the 2009 American Geophysical Union Fall Meeting were devoted to climate, and many others focused on other broad aspects of planetary change. One of these summarized climate impacts on the U.S. as reported in the 2009 report of the U.S. Global Change Research Program. It was held in a huge ballroom packed to overflowing. Judging from its program, the 2010 European Geosciences Union meeting will also present a rich set of opportunities for peering across disciplinary boundaries. And the Goldschmidt Conference programs, including the upcoming meeting in Knoxville, Tennessee, have a number of sessions relevant to the Anthropocene. Even with an understanding and appreciation of integrated science, facilitating its implementation is a challenge. Opportunities for funding research that crosses traditional discipline boundaries are increasing, but it still takes a reviewer who has a wide background and scope to react favorably to a proposal generated by an interdisciplinary scientific team, particularly one that may have contributions from social scientists. It's my hope that as we further educate ourselves on the complexities of integrated science in the Anthropocene, we might be better equipped to judge such proposals. But a real key is how we guide students who are preparing for the future. We need scientists who are capable of working in the new integrated areas of environmental science. Encouraging students to take courses in other departments is a step in the right direction, but as several authors in a recent publication argue, "If it is to nurture interdisciplinary research, graduate education must be reshaped, not just tweaked around the edges."[4] The idea of reshaping graduate science education takes many of us out of our comfort zone, but such changes are coming and should be fostered.

E. O. Wilson, one of the United States' leading scientists and environmental thinkers, called this the Century of the Environment. As Earth scientists, we have an opportunity, and perhaps even an obligation, to contribute to the fostering of integrated science in ways that benefit the planet.

Marty Goldhaber
U.S. Geological Survey, Denver
(mgold@usgs.gov)

1. Zalasiewicz J et al. (2008) Are we now living in the Anthropocene? GSA Today 18(2): 2-8
2. Rittel H, Webber M (1973) Dilemmas in a General Theory of Planning. Policy Sciences Volume 4, Elsevier, Amsterdam, pp 155-169
3. Lubchenco J (1998) Entering the century of the environment: A new social contract for science. Science 279: 491-497
4. Brint et al. (2009) Integrated Science; New Approaches to Education: A Virtual Roundtable Discussion. Springer Science Business Media, New York