Commentary: Darwin at 200

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This year marks the bicentennial of Charles Darwin's birth (February 12) and the 150th anniversary (in November) of the publication of Darwin's "extended abstract" *On the Origin of Species by Natural Selection.* Universities, scientific societies, and disciplinary journals anticipated this event by organizing meetings, theme sessions, and special issues to commemorate the anniversary. The bicentennial provides an occasion to reflect on the impact Darwin's work has for us 200 years after his birth, and it presents an opportunity, especially coming so near the start of a new year, to frame resolutions for the future. In this commentary I will offer a vision for how geoscientists and geoscience educators can respond to this opportunity.

Nature magazine (18 November 2008) solicited input from prominent research scientists, educators, and media professionals about their "great expectations" or hoped-for outcomes of a year of Darwin-centered events. Their responses reflected the central role that science education holds for realizing these outcomes:

- Patricia Adair Gowaty, Distinguished professor, Ecology and Evolutionary Biology and Institute of the Environment, UCLA hopes for "enhanced public understanding of Darwin and the nature of science" resulting in "quicker resolution of continuously re-emerging controversies" between scientists and "creation scientists."
- Per-Edvin Persson, Director, Heureka, the Finnish Science Centre, Finland, envisions a day in which "the majority of the world's population will understand that evolution is the process by which diversity of life is maintained on this planet." The evidence that this day has arrived will be a "diminished number of attacks on science from non-scientific sources."
- Michael Lynch, Distinguished professor in the Department of Biology, Indiana University, Bloomington, would like to see increased understanding that our view of evolution has evolved in 150 years, which "will require the education of a new generation of scientists in the basic principles of evolutionary theory that have emerge since Darwin."

Communicating the nature of science to students and the general public is within the purview of scientists and science educators of all disciplines, but together with our colleagues in the biological sciences, geoscientists and geoscience educators bear much of the responsibility for increasing public understanding of the contributions of Charles Darwin and the advances made in evolutionary theory in the 150 years since the *Origin* because we are the keepers of primary data for evolution. Any failure to realize the "great expectations" expressed above reflects on our respective disciplines and on our ability to communicate to our students and the general public just exactly what it is that we do.

Advances in molecular, cell, and developmental biology yield new understanding of sources of variation and selection that drive evolution but the most accessible, hands-on evidence for evolution comes from fossils and rocks—the geologic record of life on Earth and the physical record of changes in environments over geologic time. Indeed, most students will encounter fossils in their classrooms as evidence of change through time (e.g. grade 4 in Michigan benchmarks) before tackling genetics and developmental biology. This is a great opportunity and great responsibility for geoscience educators. We have the means for realizing the "great expectations" listed above, and the action plan for achieving these ideals is within the grasp of every educator. What follows is a vision for geoscience education in the United States modeled on the shared great expectations briefly outlined above:

1. **Students** will live and breathe the *nature of science* in every geoscience class and in so doing will replace their misconceptions about science with new understanding and consequently will sharpen their ability to separate science from non-science. This is not a call for a re-hashing of the scientific method, but for amplification and expansion of its precepts, especially falsifiability of hypotheses, through direct connection with the course content. Students need to be able to answer the question "how do we know this" and "what are the data that support this" for each hypothesis. The vocabulary of science (especially the word "theory") will be reinforced with copious references to specific examples and the data that support those examples. The history of science is littered with the corpses of once-favored theories toppled by later new understanding. These stories will be used to emphasize science as a human endeavor (subject to error, misjudgment and fraud-usually the stories that captivate our students) and the self-correcting nature of science, which distinguishes it from other ways of understanding (philosophy, religion).

Geoscience is rich with examples and primary data to realize this first expectation. The history of the development of plate tectonic theory demonstrates the dynamic nature of science. Students' understanding of what science is and how science "works" is deepened by tracing the evolution of the modern theory from Wegener's original hypothesis of Continental Drift, examining the reasons why this early hypothesis ultimately rejected, and following the serendipitous route of discovery (e.g., the discovery of symmetrical magnetic stripes on the ocean floor around the mid-ocean ridges), that led to our modern understanding of how the Earth works. The power of plate tectonic theory is reinforced by a plethora of disparate geological phenomena that are linked by the theory, including all the observations that Wegener made (apparent fit of the Gondwanan continents, the structural match of mountain belts on opposite sides of the Atlantic, disjunct fossil distributions, etc.) plus all the advances since Wegener (age of the ocean floor, ocean floor topography, etc.).

The excitement of discovering Earth's changes

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through time is also accessible to earlier (pre-plate tectonic curriculum) classes. The "three types of rocks" become more than a memorization exercise when students understand that the rocks represent past environments—a volcano, a beach, a coal swamp, an ancient mountain range—and can compare the classroom hand samples to sediments and rocks from different modern geological settings. And of course, fossils are very powerful tools in conveying the concept of organic change through time, which leads to the next expectation.

2. Teachers will *fully engage students of every philosophical persuasion* in discussions of why non-science ideologies like intelligent design fall short of science and do not belong in the science classroom. This point is moot if students have already internalized the nature of science (expectation 1, above). False choices, such as invoking the "fairness issue" for presenting both scientific and non-scientific ideas and "letting the students make up their own minds", will diminish as teachers' own understanding of the nature of science is deepened by the institution of expection 1.

The "how do we know" question often becomes a challenge raised by students in reference to the history of life (as in, "How do you know—nobody was around then"). Teaching evolution and the history of life is fraught with political, social, and students' own personal baggage. That this baggage is unnecessary, that science and religion occupy what Stephen Jay Gould (1997) termed, "non-overlapping magisteria", unfortunately is beside the point—this baggage exists, and geoscience educators are on the front line, called to deal with it. It is not enough that "nothing in biology [or the history of life] makes sense except in light of evolution" (Dobzhansky, 1973); many students struggle to make sense of a perceived conflict between personal or family beliefs and evolution. Their dilemma can be addressed in the geoscience classroom by teachers defusing the "E" word, taking it out of the narrow context of the biology/history of life use and expanding it to include the evolution of the Earth (plate tectonic theory) to the evolution of the solar system (solar nebular theory) and ultimately to the origin and evolution of the universe (Big Bang theory). Internalizing the fact that "everything evolves" eases the path for both geoscience students and teachers. K-12 teachers who have participated in professional development that models this "Evolution of Everything" paradigm (Brandt, 2008) reported more confidence in their ability to deal with the "E" word in all its contexts.

3. The role of research in geoscience and geoscience education frames the final expectation. Individual **researchers** will acknowledge that in addition to our peers and granting agencies we owe summaries of the major findings and contributions and/or implications of our work to another audience, the general public, and make a commitment to *disseminate research results in a clear and accessible manner* to this audience. The pages of this journal offer one such outlet. Technology can facilitate this task, e.g., webpages, podcasts, online-video, but should not replace face-to-face relationships between researchers and K-12 teachers and their students. The National Science Foundation supports these interactions through outreach supplements to disseminate the results of NSF-sponsored research.

We celebrate Charles' Darwin's birthday after 200 years because of the vigor of his ideas and his dedication to communicating those ideas to the general public. The strength of Darwin's hypotheses stemmed from the myriad data he had gleaned from his close observations of the natural world and his insatiable appetite as an experimentalist, from breeding pigeons to documenting the effect of sound on earthworms, to observing the behavior of his own children. Geological observations were an important part of Darwin's personal voyage of discovery of evolution by natural selection, and the data of geoscience remain of utmost importance in understanding and embracing the evolution of, and interactions between, the geosphere and biosphere.

Darwin was a prolific correspondent in a pre-digital age. The Darwin Correspondence project has logged over 5000 letters (http://www.darwinproject.ac.uk/; also see the cover photo for this issue). If the geosciences are to thrive over the next 200 years we would do well to follow the principles of observation, inquiry, and communication modeled by Mr. Darwin.

REFERENCES

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