

Postlude

May R. Berenbaum

MAY R. BERENBAUM, a Fellow of the American Academy since 1996, is Professor and Head of the Department of Entomology at the University of Illinois at Urbana-Champaign. She is interested in the chemical interactions between herbivorous insects and their host-plants, and the implications of such interactions on the organization of natural communities and the evolution of species. She has published more than two hundred articles in refereed scientific journals as well as six books about insects for the general public, including *The Earwig's Tail: A Modern Bestiary of Multi-Legged Legends* (2009), *Buzzwords: A Scientist Muses on Sex, Bugs, and Rock 'n' Roll* (2000), and *Bugs in the System: Insects and Their Impact on Human Affairs* (1994).

The essays in this issue are tributes to the ability of their scientist-authors to highlight and summarize the exciting developments within their own areas of expertise, and then to explain those developments in a clear and accessible manner. Moreover, they are tributes to the courage of these authors; predicting the future, even that of a scientific field, is an inherently unscientific enterprise. The conduct of science depends on cold, hard, verifiable facts, and forecasting the future is necessarily rife with uncertainty. This may partly explain why predicting the future of science has often been the province of non-scientists. For example, it was a French professor of Hebrew, Syriac, and Chaldaic at the Collège de France, one Ernest Renan, who in 1890 penned the essay, “The Future of Science.”¹ (This was a man initially trained for the priesthood, no less, and whose best-known work was *Life of Jesus*, one volume in a series on the history of Christianity.) Profession notwithstanding, Renan insightfully wrote, “Science will always remain the gratification of the noblest craving of our nature; curiosity; it will always supply man with the sole means of improving his lot” – a sentiment that our scientist-essayists certainly would endorse.

On this side of the Atlantic, Charles August Kraus was one of the first scientists to anticipate the future of the scientific enterprise. A professor of chemistry at Clark University, Kraus presented “The Future of Science in America” on February 1, 1917, in honor of Founder’s Day at his home insti-

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The scientist, to be worthy of the name, must be possessed of an insatiable desire to extend knowledge in its most fundamental aspects. He must not count the years of preparation required to actually master his subject, nor the labor necessary to transmute a crude idea into a well polished, finished scientific product. He must never be satisfied with mediocrity, and must ever strive to increase his scope in order that he may produce results of more fundamental importance.²

Kraus went on to conduct supremely useful chemical research, directing the Chemical Warfare Service at Clark during World War I, after which he left for Brown University, consulted on the Manhattan Project, and helped develop, among other things, the atomic bomb, Pyrex glass, leaded gasoline, and ultraviolet lamps.

Our essayists would agree with another century-old prediction: namely, that much remains to be learned. Renowned geneticist J.B.S. Haldane addressed this issue in his 1924 essay, aptly named “Daedalus; or, Science and the Future”:

The possibility has been suggested – I do not know how seriously – that the progress of science may cease through lack of new problems for investigation. Mr. [G. K.] Chesterton in *The Napoleon of Notting Hill*, a book written fifteen years or so ago, prophesied that hansom-cabs would still be in existence a hundred years hence owing to a cessation of invention. Within six years there was a hansom-cab in a museum, and now that romantic but tardy vehicle is a memory like the trireme, the velocipede, and the 1907 Voisin biplane. I do not suggest that Mr. Chesterton be dragged – a heavier Hector – behind the last hansom cab, but I do contend that, in so far as he claims to be a prophet rather than the voice of one cry-

ing in the wilderness, he may be regarded as negligible for the purposes of our discussion. I shall try shortly to show how far from complete are any branches of science at the present time.³

Our twenty-first-century collection of essays similarly celebrates the power and beauty of basic research and its ever-receding frontiers. A common theme is that the boundaries of scientific knowledge are elastic, in all directions. Little-known Latinate prefixes are now common parlance; technology is nanoscale; and flyby spacecraft missions require the use of distance measures equivalent to “thirty times the Earth’s distance from the sun” (that distance, 93 million miles or 150 million kilometers, is referred to as an “astronomical unit”). New vocabulary demonstrates how our knowledge is expanding: every essay contains words that would have been meaningless to Russell, Haldane, and other eminent twentieth-century authors attempting to predict the future of science. All the essayists in this volume anticipate continuing advances, with the expectation that frontiers in their respective fields will be pushed back at an accelerating pace.

The essayists writing at the turn of the last century were in agreement that predicting the utility of basic science is difficult. Haldane stated, “It is perhaps interesting to speculate on the practical consequences of Einstein’s discovery.” He might have been surprised by the many practical consequences of Einstein’s fundamental insights, not the least of which involve nuclear fission, fusion, global positioning systems, and even semiconductors. Philosopher-mathematician Bertrand Russell, in his 1924 response to Haldane’s essay, “Icarus; or, The Future of Science,” specifically cited “Darwinism” when he wrote: “The effect of the biological sciences, so far, has been very small. . . . It is

probable that great effects will come from these sciences sooner or later.”⁴ Nearly one hundred years later, Russell’s prediction has proven true. Indeed, understanding evolution is essential to comprehending much of the subject matter in this volume, including genomic science and its applicability toward curing human diseases as well as genetically modifying plants; microbial science and contributions of biofilms to microbial pathogenesis; shared developmental pathways involving limb development; and even estimating the probability of life in other solar systems.

Both Haldane and Russell were also well aware of the fact that, beyond being difficult to predict, the utility of scientific advances often depends on the political and social environments in which they are made. Russell’s essay begins with a dire prediction: “Much as I would like to agree with [Haldane’s] forecast, a long experience of statesmen and governments has made me somewhat skeptical. I am compelled to fear that science will be used to promote the power of dominant groups, rather than to make men happy.” Today, as in the twentieth century, how (and even whether) scientific advances are used depends to an enormous extent on that substantial majority of the population who are not scientists. In this respect, I can confidently make one prediction that I believe will withstand the test of time: without a well-educated public, the future of science in the United States is bleak.

The U.S. scientific enterprise, more so than in most nations, depends on a public not only supportive of federal funding for basic research but also capable of crafting and adopting policies based on solid science. So with knowledge expanding at such a rapid pace, can the vast majority of Americans who are not professional scientists keep up? There are disturbing indi-

cators that a gap is widening between scientists and the general public. According to a 2006 study, less than 40 percent of Americans understand the concept of evolution by common descent – a proportion lower than that of any other industrialized nation.⁵ A lack of understanding of such a well-supported, widely accepted fundamental scientific principle could undermine the future productivity of science writ large. Moreover, there are indications that the problem in the American public is more than not understanding; tolerance (even encouragement) of willful rejection of well-established science is on the rise. One-third of Americans polled averred that evolution is “absolutely false,” a significantly higher proportion than in any other Western country.

Our competitiveness as a nation in the twenty-first century depends, much as it did in the twentieth century, on the ability of scientific advances to improve the human condition; and the viability of the scientific enterprise depends on an informed and supportive electorate. Our peculiar outlier status among the scientifically advanced nations of the world with regard to evolutionary theory is symptomatic of a larger problem: that is, fewer than one in five Americans possesses the background skills required to read an article about science in a newspaper, follow a television program on a scientific subject, or understand a popular science book.⁶

Perhaps even more important than knowing scientific facts is understanding the scientific process – that theories have predictive power yet are provisional, that there are many ways to test hypotheses, and that conclusions must be based on strong and repeatable evidence. In a recent report based on the 2012 *Science and Engineering Indicators*, the National Science Foundation revealed that a significant number of Americans tested on their

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Fortunately, there is reason for optimism. The same survey that revealed problems with American understanding of scientific methods has for three decades shown that Americans understand why basic science is important. Over the years, the *Science and Engineering Indicators* surveys have asked Americans whether “even if it brings no immediate benefits, scientific research that advances the frontiers of knowledge is necessary and should be supported by the Federal Government”;

remarkably, the proportion who agree has continued to rise, reaching 84 percent in 2008. Moreover, the 11 percent of respondents in 2006 and 2008 who felt that the federal government invested too much in research represented “the lowest levels registered since 1981.”

Haldane wrote in 1924 that “we must educate our poets and artists in science.” To that sentiment, which we heartily endorse, we add that we must educate everyone in science; this mission includes educating our scientists beyond the boundaries of their own disciplines. We hope that our contributors, in presenting their vision of science in the twenty-first century, have succeeded in stirring that “noblest craving of our nature” – curiosity – our best investment for a happy, healthy, and well-informed future.

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ENDNOTES

- ¹ Ernest Renan, “The Future of Science: Ideas of 1848,” translated from the French (London: Chapman and Hall, 1891). Biographical information on Ernest Renan is from “Notes & Obituary Notes,” *Popular Science Monthly* 42 (December 1892).
- ² Charles August Kraus, “The Future of Science in America: An Address Delivered on Founder’s Day February 1, 1917,” Publications of the Clark University Library, vol. 5, no. 3 (Worcester, Mass.: Clark University Press, 1917), <http://www.archive.org/details/futureofscienceiokkraurich>.
- ³ J.B.S. Haldane, “Daedalus; or, Science and the Future,” a paper read to the Heretics, Cambridge, on February 4, 1923 (London: K. Paul, Trench, Trubner, 1925).
- ⁴ Bertrand Russell, “Icarus; or, The Future of Science” (London: K. Paul, Trench, Trubner, 1924).
- ⁵ Jon D. Miller, Eugenie C. Scott, and Shinji Okamoto, “Public Acceptance of Evolution,” policy forum, *Science* 313 (5788) (August 2006): 765 – 766.
- ⁶ Jon D. Miller, “Civic Scientific Literacy: A Necessity in the 21st Century,” *FAS Public Interest Report: The Journal of the Federation of American Scientists* 55 (2002): 3 – 6.
- ⁷ National Science Foundation Science Board, *Science and Engineering Indicators*, 2012, <http://www.nsf.gov/statistics/seind12/>.