BOOK REVIEWS

The Candle and the Darkness

The Demon-Haunted World. Science as a Candle in the Dark. CARL SAGAN. Random House, New York, 1996. xviii, 460 pp. $25.95 or C$35.95.

In 1961 while driving at night in the White Mountains, Betty and Barney Hill sighted a bright object in the sky that seemed to follow them. Fearing for their safety, they left the main highway and took narrow roads, arriving home two hours later than they had expected. The experience prompted Betty to read a book that described UFOs as spaceships navigated by little men from other worlds, who sometimes abducted humans. Soon thereafter, she began experiencing a repetitive nightmare in which she and Barney were abducted and taken aboard a UFO. In a few days they were describing a pancake-like UFO with uniformed figures visible through the craft's windows. This and other motifs of the Hills' account are similar to those found in the 1953 motion picture *Invaders from Mars*. Later, Barney described the enormous eyes of the aliens, just 12 days after aliens were so portrayed in an episode of the television series *The Outer Limits*. The Hills' story was made into a 1975 movie purporting that short, gray alien abductors are among us in the psyches of millions of people.

Carl Sagan tells that he met with the Hills for several hours, and writes: "There was no mistaking the earnestness and sincerity of Betsy and Barney, and their mixed feelings about becoming public figures" (p. 103). Nevertheless, there are many reasons to doubt that the events described by the Hills happened in the world outside their mental experience. Sagan pursues this and other case histories of a demon-haunted world with the surefootedness of a well-informed observer, the narrative skills of an engaging raconteur, and the subtle destructiveness of an experienced educator.

We encounter the Man in the Moon, the Face of Mars, the Dragon in the Garage, and countless stories of UFO sightings, abductions by aliens, and miraculous apparitions. Sagan meticulously debunks each story by noting absence of verifiable information, uncovering suspicious coincidence of conditioning circumstances, and pursuing other lines of reasoning that would persuade an impartial reader that the claimed experiences resulted from dreams and hallucinations, rather than from events in the outside world. We are provided a long list of typical offerings at the table of pseudoscience and superstition: astrology, the Bermuda Triangle, Big Foot, the Loch Ness monster, extrasensory perception, bleeding statues, divining rods, pyramidology, palmistry, numerology, faith-healers, Ouija boards, and much more.

Sagan tackles antiscience, in addition to pseudoscience. Science has been under attack for centuries, he proclaims. The nemeses of our time are postmodernists and deconstructionists (he does not use the latter term) who deny the objectivity of science. "Some even allege," he laments, "it's entirely subjective, as is, they say, history" (p. 252). Sagan sees that historical accounts are often self-promotional; what really happened is colored by subjective biases. Scientists also have biases and breathe the prevailing prejudices of their environment. But science is a collective enterprise endowed with the error-correcting process of empirical testing. In science, "you can rerun the event as many times as you like, examine it in new ways, test a wide range of alternative hypotheses" (p. 254). Scientists are biased and commit mistakes, but "Science thrives on errors, cutting them away one by one. False conclusions are drawn all the time, but they are drawn tentatively. Hypotheses are framed so they are capable of being disproved" (p. 20).

Science is the candle in the dark of the book's title, and Sagan seeks to characterize its distinctive attributes. One, according to him, is that science can predict the future. "Not every branch of science can foretell the future—paleontology can't—but many can and with stunning accuracy. If you want to know when the next eclipse of the Sun will be, you might try magicians or mystics, but you'll do much better with scientists" (p. 30). Here Sagan and I part company. In the matter of foretelling the future I don't think that astronomy is the rule and paleontology the exception, but the other way around.

Scientists predict the course of rockets and the statistical distribution of populational events, but that is in my book a long way from foretelling the future. Yet I think it correct to assert that "science is predictive," as the slogan goes. Indeed, being predictive of unknown facts is essential to the process of empirical testing of hypotheses, the most distinctive feature of the scientific enterprise. A hypothesis is tested empirically by ascertaining whether or not predictions about the world of experience derived as logical consequences from the hypothesis agree with what actually becomes observed. What is being predicted in this process is an unknown state of affairs, not necessarily a future event. And the prediction is made by logical deduction from the hypothesis.

The hypothesis that chimps are more closely related to humans than to gorillas is tested by examining DNA segments from each species, which the hypothesis predicts will be more similar between human and chimp than between chimp and gorilla. The evolutionary divergence of humans, chimps, and gorillas happened in the distant past, and their DNA is already there. When I now examine it, I test my hypothesis. Sagan has gone astray by failing to distinguish prediction in the logical sense (by deduction) from prediction in the temporal sense (foretelling the future), which is not an essential feature of science.

Sagan has much to say about reductionism as a distinctive feature of science that accounts for much of its success. Science seeks understanding of an event or process by investigating its component elements and underlying processes. The success of this analytical mode is unquestionable (although the antithetical mode is also successful; in matters of research strategy, what counts is success, not how we get there). We might call this kind of research strategy "methodological" or "strategical" reductionism.

But Sagan claims much more. He writes: "Until the middle twentieth century, there had been a strong belief . . . that life was not 'reducible' to the laws of physics and chemistry, that there was a 'vital force,' an 'entelechy,' a tao, a mana that made living things go" (p. 271). He tells the story of the 18th-century chemist Joseph Priestley, who found no difference in the weight of a mouse just before and after its death. Nothing had departed with death, at least nothing that could be weighed. Most scientists would agree, I suppose, with this kind of reductionism (let's call it "ontological" or "physical"). Living things are exhaustively composed of atoms; if we remove all the atoms that make up a mouse body, nothing is left. But accepting this kind of reductionism does not in any way entail the claim that biology is reducible to the laws of physics and chemistry. This is an epistemological claim, which can be shown to be mistaken

by simply pointing out that the origin of species or symbolic language (or the majority of the subjects worth of investigating in biology and other disciplines) cannot be explained by the laws of physics or chemistry.

Sagan might state a conviction that such reductionism (of, say, the laws of biology to the laws of physics) will be accomplished in the future. But this is a statement of faith. The late philosopher Karl Popper argued that complete epistemological reduction of a discipline to another is impossible in principle. Sagan asks rhetorically: "Why should some religious people oppose the reductionist program in science, except out of some misplaced love of mysticism?" Popper's opposition to the (epistemological) reductionist program in science was certainly not religiously motivated, nor was he particularly appreciative of mysticism.

Francisco J. Ayala
Department of Ecology and Evolution, University of California, Irvine, CA 92697, USA

Vignettes: Identity Crisis

The myth of human exceptionality has been supplanted of late by the myth of biological continuity. Recent research efforts in the social and natural sciences seem determined to prove—indeed, presume to have already proved—that there is no essential, irreducible distinction between humans and animals. Each one of our prized facilities—language, cognition, megalothymia—is shown to appertain in one degree or another to other species. Precisely at the moment when we have overcome the earth and become unearthly in our modes of dwelling, precisely when we are on the verge of becoming cyborgs, we insist on our kinship with the animal world. We suffer these days from a new form of collective anxiety: species loneliness.

—*Robert P. Harrison*, in *Uncommon Ground: Toward Reinventing Nature* (William Cronon, Ed.; Norton)

Thinking in terms of bits has allowed us to develop the field of computer science, in which we learn how to represent the world with patterns of information. So successful are our endeavors that some physicists and computer scientists believe that perhaps information is not a human invention but something as real, as physical, as matter and energy. And now a handful of researchers have come to believe that information may be the most real of all. Simulated creatures would have no way of knowing they are simulations, the argument goes. And, for that matter, how do we know that we are not simulations ourselves, running on a computer in some other universe?

Nature, it seems, has honed us into informavores so voracious that some can persuade themselves that there is nothing but information.

—*George Johnson*, in *Fire in the Mind: Science, Faith, and the Search for Order* (Knopf)

The Gender Front

The Equity Equation. Fostering the Advancement of Women in the Sciences, Mathematics, and Engineering. CINDA-SUE DAVIS, ANGELA B. GINORIO, CAROL S. HOLLENSHEAD, BARBARA B. LAZARUS, PAULA M. RAYMAN, and associates. Jossey-Bass, San Francisco, CA, 1996. xxx, 353 pp., illus. $36.95. Jossey-Bass Higher and Adult Education.

Much attention has been paid to women's underrepresentation in the sciences, mathematics, and engineering (SME) in the past decade. Those who have a long-standing interest in the subject will find *The Equity Equation* a good update. For readers who are new to the subject, the book serves well as an entry point.

The Equity Equation is a collection of papers that were originally prepared for a 1994 conference sponsored by the Cross University Research in Engineering and Science group on women and gender, with the support of the Alfred P. Sloan Foundation. The book consists of nine substantive chapters and a summary chapter. The substantive chapters follow a consistent format: a literature review followed by the authors' view of needed research and policy interventions in the future. The authors have long been concerned with gender equity in SME, and their past contributions to the subject are cited in the book. In the first chapter, Daryl E. Chubin and Shirley M. Malcom propose structural remedies that they believe will promote women in science. Betty M. Vetter provides an overview of gender differences in SME. Three separate chapters are devoted to science education: Jane Butler Kahle focuses on the elementary and secondary levels, Helen S. Astin and Linda J. Sax on the undergraduate level, and Carol S. Hollenshead, Stacy A. Wenzel, Barbara B. Lazarus, and Indira Nair on the graduate level. Beatriz Chu Clewell and Angela B. Ginorio's chapter is concerned with the intersection of gender and other dimensions of diversity, with an emphasis on race. Cinda-Sue Davis and Sue V. Rosser review program and curricular interventions. Mary Frank Fox's and Paula M. Rayman and Jennifer S. Jackson's chapters cover women scientists in academia and in industry respectively.

The book's principal value lies in its summary and critique of the literature on women in SME. However, the book does not stop here. It also aims to set the future research and policy agenda, and this aim is fully explicated in the final chapter, by Hollenshead, Wenzel, Margaret N. Dykens, Davis, Ginorio, Lazarus, and Rayman. The authors recommend five research areas requiring future attention: "collection and dissemination of disaggregated data, examining of nonacademic careers, evaluation of intervention programs, development of an institutional perspective, and examination of true entry points or gateways into science careers" (pp. 322–23). These are important areas, and I am particularly sympathetic with the last two concerns. The authors' explication of them is less than satisfactory, however. For example, their definition of "an institutional perspective" exclusively focuses on employers in local settings. A broad institutional perspective should incorporate rules and norms operating at the societal level. In addition, in discussing evaluation research, the authors overlook methodological pitfalls that are well recognized in statistics, economics, and sociology: the nonexperimental nature of intervention programs renders observed data, quantitative or qualitative, prone to selection biases and subject to alternative interpretations. Finally, the authors' call for the collection of new data is not fully justified, given the vast amounts of existing unit-record data that have not been fully explored for the study of women in SME, either by the authors or by other researchers. Such data sets include the