Gerald Holton
Guest Editor's Introduction

AT FIRST BLUSH, "SCIENCE" AND "ERROR" SEEM TO BE POLAR OPPOSITES—the one a heroic pursuit of provable and widely sharable truths, the other a miserable exemplar of human frailty. The very definition of the two terms mirrors that polarity, with the august *Oxford English Dictionary* declaring science to be "knowledge acquired by study; acquaintance with or mastery of any department of learning." Error is defined as "the holding of mistaken notions or beliefs" and, the *OED* adds, solemnly, "a departure from moral rectitude; a transgression, wrong doing." Even viewed historically, the two concepts have long dwelled in opposite quadrants of respectability. The exposure, especially in the early seventeenth century, that ancient wisdom was riddled with fundamental flaws, provided the warrant for newborn science to grow soon into a veritable juggernaut—as elegantly set forth in the first of the essays in this volume.

That success led many scientists and philosophers, especially in Germany, to a view of their calling, cresting in the first half of the nineteenth century but persevering much longer, which amounted to a quasi-religious amplification of science, a form of sacralization. At its height it was said explicitly to endow scientists with the role of "priests of nature," laboring in the "Temple of Science," where they worked on the temple's completion so as to make it representative of the scientific model of the world itself. That self-imposed service was generally traced back metaphorically to the demands of the temple's chief goddess, Isis, the mother of the universe, who had presided over the beginning of civilization in ancient Egypt and therefore stood for wisdom itself. In that context, a scientist's error would be equivalent to heresy.

The use of such language by some of the most eminent scientists of the day, even into the early part of the twentieth century, such as Wilhelm Ostwald's "Science takes the place of the divine," now seems uncomfortable at the very least. But it was in good part an attempt to help establish the standard norms of scientific conduct while also inoculating science against those who for various reasons were hostile to what they perceived to be the triumphalist assumption of an overarching epistemological authority by science.

But ironically, all along, and to this very day, scientists have known in their very bones that this elevating metaphor is quite at odds with the actual pursuit of scientific research. To be sure, in those moments when the work at last succeeds, the ensuing euphoria makes the pain endured during all the intermediate steps seem worth it, and even an analogy to a religious experience may assert itself.

But on the way to those rare eureka moments, practitioners of science know well that the path is strewn with hurdles and pitfalls, costly detours, with minor and major blunders and gremlins in the experimental equipment or in the theoretical presuppositions. The search may be so long and tedious, so demanding on one's energy and spirit, that one of the persistent words in scientists' private correspondence is "despair." As Stephen Gould once remarked about some biological research, "Over 90 percent of the day's work generally turns out to be for naught, and then you still have to clean out the mouse cage." A perhaps more elegant way to put this perception is that of Goethe's Faust, who discovers that human affairs are constantly apt to be misdirected owing to the innate dialectic by which each positive advance has to battle with the "spirit that ever negates."

But all this is being kept quiet from the public, and does not show up in the scientific literature. As Peter Medawar, in his brilliant book, *The Art of the Soluble,* put it, "It is no use looking to scientific 'papers,' for they not merely conceal but actively misrepresent the reasoning that goes in the work they describe." And P. A. M. Dirac, then the dean of physicists, made this frank confession in a 1972 essay:

> The research physicist, if he has made a discovery, is then concerned with standing on the new vantage point which he has gained and surveying the field in front of him. His question is: where do we go from here? . . . He wants to rather forget the way by which he attained this discovery. He proceeded along a tortuous path, followed various false trails, and he does not want to think of these. He feels perhaps a bit ashamed, disgusted with himself, that he took so long. . . . With that point of view, one does not want to remember all the work that led up to the making of the discovery. Now, that is just the opposite to what the historian of science wants. He wants to know the various influences at work, the various intermediate steps, and he may even have some interest in the false trails. These are quite contradictory points of view.

These rare testimonies target error as the unpleasant but unavoidable cousin of scientific research, or as sort of an entropy tax that attaches itself almost automatically during any effort intending to do good work. Yet, a long fashionable view among some philosophers, guided by Karl Popper, has assigned to error an even more sinister role. Popper's well-known "falsification" program posits that an inherent possibility of finding a statement to be false is the very test of its being truly scientific (as could not be the case, in his view, for example with any statement by a communist or psychoanalyst). Popper asks therefore that as soon as a particular scientist has given birth to a hypothesis, she should get busy and dig, next to the new cradle of the much-admired infant, a grave into which it may be tossed. Nothing deserves the appellation of science in the absence of a possible test whether it can be killed.

But of all the blunders that beset the labors of scientists, there is one type that seems to me the least discussed yet the most fascinating. It is the "big error," so big that only a very good natural or social scientist can commit it—but which, far from stopping the progress of science, even propels it eventually to a major advance. It is an ultimately fruitful mistake, close to a proposition ascribed to Francis Bacon: Truth comes more easily out of error than out of confusion.

When Arien Mack, the editor of this distinguished quarterly, remarked to me that her journal might be a good place to explore this very subject, and asked me to help out as guest editor, I was attracted to the idea of showing by case studies that as science progresses in its quasi-evolutionary way, many unsuccessful efforts die, but some findings that in retrospect look pathetically deficient or even wrong, turn out to have led to real advances. Examples from the history of science abound:

- Tycho Brahe collects excellent data on the orbits of the planets in the service of his wrong model of the solar system, but the data lead Johannes Kepler to find the right model.
- Hans Christian Oersted, having misinterpreted Kant on the ideas of a fundamental force, is led by it to discover the synthesis of electricity and magnetism, thereby unwittingly launching the second Industrial Revolution by making possible motors and generators.
- John Dalton misreads Isaac Newton on gases, and so is led to ideas that make him the founder of modern chemistry.
- Henry Becquerel wrongly believes that his uranium ore emits ordinary X-rays, and drops the matter; Marie Curie suspects that another process is at work, and so (working with Pierre Curie) discovers and names radioactivity.
- Guglielmo Marconi succeeds in sending the first radio message from America to Europe, contrary to contemporary certainty that the earth's curvature should have caused the signal to go straight off into space; only later is the ionosphere discovered that reflects the signal. But Marconi has taken the first step to our subsequent inundation of long-range wireless messages, from radio and television to cell phones.
- Albert Einstein is on the wrong track for decades trying to find a unified field theory, but so helps to set the agenda for discover-

ing the unification of all forces of physical science. And in 1917, Einstein finds that his general relativity theory predicts an unstable universe, one that could collapse or expand. He therefore famously inserts a "cosmological term," purely ad hoc, to prevent those alternatives. But he reportedly called this his "greatest blunder" when in 1929 E. Hubble discovered the expansion experimentally. Yet, some years ago a cosmological term had to be restored, when the *acceleration* of the expansion was discovered.

- Niels Bohr introduces the idea of the shape-changing nucleus when it is excited, but only others use it to explain fission, leaving him to slap his forehead, saying "of course, I should have. . . ."
- Erwin Schrödinger's influential book, *What Is Life?* (1945) wrestles with the question of the stability of genetic material, but cannot show how it might replicate. Linus Pauling grasps the mechanism of complementary templates, but proposes a three-stranded structure for DNA—a big mistake that drove James Watson and Francis Crick to the discovery of the double helix.

Several of these cases, and others of similar portent, are presented in the chapters that follow. Some essays have the general shape, "It was from the ashes of distinguished researcher *X*'s failed attempt to find *A* that another distinguished researcher, *Y*, was able to establish *B*, thus securing one of the important advances over the previous, standard model." We shall read here cases where real failures helped to bring to fruition some of the major advances in the sciences: nothing less than the discovery of the structure of the solar system; of the atomic theory of chemistry; of radioactivity; of long-distance radio waves; of steps toward the realization of nuclear weapons; of the untenability of racist anthropology; of an understanding of altruism; and more.

The feast awaits you. Bon appetite.