1 Setting the stage

This is a book about uncertainty, particularly the uncertainty we associate with science. Over the years, scientific uncertainty has been addressed by natural scientists, engineers, medical researchers, social scientists, and philosophers. But for all the perspectives that have been laid out in everything from short essays to scholarly monographs, the richness of scientific uncertainty has often been unappreciated and/or misunderstood by the general public, people not regularly engaged in science.

Uncertainty, of course, is not confined to the world of science. It is an everyday fact of ordinary life as well. We regularly face uncertainty in a myriad of ways. Will it rain today? Will Aunt Dorothy's plane arrive on time? Will the stock market tumble? Will an accident snarl the freeway during rush hour? These day-to-day uncertainties come and go, and we move on through life, sometimes preparing for them, but more often just plowing through them.

But uncertainty also colors longer-term concerns. Will my pension program be sufficient two decades from now to enable the full and comfortable life that my wife and I hope for? Will our health allow a free and independent life-style thirty years in the future? These longer-term questions are harder to answer and are cloaked in greater uncertainty. Because we have only one life to live we cannot return to 'Go' and take another path. Of necessity, we must plan, make decisions, and do our best, all the while evaluating our actions and making mid-course corrections according to our best judgment at the time.

Uncertainty is hardly confined to the future alone; it characterizes our knowledge of the past as well. Adopted children wonder about their birth-parentage, families have difficulty reconstructing the circumstances that led great-grandparents to emigrate. Military

historians continue to reconstruct various scenarios for General Gordon's last days in Khartoum, or for Major Custer's last stand in the hills overlooking the Little Bighorn. Geologists are far from settled about the causes of ice ages, and paleontologists still debate the evolution of birds. Our understanding of the past is uncertain because the record of the past is incomplete and to some degree inaccurate. Often the evidence that we do have appears contradictory.

Throughout life, people are immersed in uncertainty. They routinely accommodate the uncertainty with a variety of rational, accepting and non-hostile responses. At a simple level, an urbanite might carry an umbrella to meet the possibility of rain; at a more complex level, a farmer might participate in a commodity futures market to protect against the possibility of a drought. Retirement fund managers routinely make investment decisions in the face of considerable long-term economic and political uncertainty, and home and car owners purchase insurance to protect against catastrophe in an unpredictable future. These are all rational actions taken in the face of uncertainty. Nevertheless, there is sometimes a reluctance on the part of decision-makers to take actions addressing complex science-based issues in the face of similar levels of uncertainty, in part because they feel inadequately prepared to contextualize and evaluate the attendant scientific uncertainty. The topic of global climate change illustrates both the scientific complexities and uncertainties, and the difficulties that people and nations have in formulating rational policy addressing the many facets of a changing climate on Earth.

Several themes will run through the chapters of this book, which more or less define my perspectives on accommodating uncertainty, whether ordinary or scientific:

- Uncertainty is always with us and can never be fully eliminated from our lives, either individually or collectively as a society. Our understanding of the past and our anticipation of the future will always be obscured by uncertainty.

- Because uncertainty never disappears, decisions about the future, big and small, must always be made in the absence of certainty. Waiting until uncertainty is eliminated before making decisions is an implicit endorsement of the *status quo*, and often an excuse for maintaining it.
- Predicting the long-term future is a perilous business, and seldom do the predictions fall very close to reality. As the future unfolds, 'mid-course corrections' can be made that take into account new information and new developments.
- Uncertainty, far from being a barrier to progress, is actually a strong stimulus for, and an important ingredient of, creativity.

THE GARDEN OF UNCERTAINTY

Throughout this book, you will be taken on some scientific excursions that will illustrate how uncertainty is woven into the fabric of the scientific enterprise. Many of these treks will be in the Earth and environmental sciences, the field in which I have lived my scientific career. In particular, there will be many forays into that contemporary topic of almost universal interest – global climate change. Probably no other scientific topic has been more regularly in the spotlight during the 1990s than global climate change, and intense debate has swirled around it. The issues of focus at various times have been the reality of climate change, the causes, the consequences, and the political, economic, and social responses to it. As a global scale, complex, slowly developing phenomenon, it displays many of the fascinating facets of scientific uncertainty in general, and it shows how scientists work and thrive in an environment of uncertainty.

The scientific excursions laid out in this book can be thought of as outings in 'the garden of uncertainty', explorations of a vast and irregular tract comprising established plots of annuals and perennials, some newly plowed ground, rare specimens, weeds, thickets, and mazes. Each area of the garden reveals a different facet of uncertainty. And for every insight about uncertainty that one may draw from

science, there is usually a parallel and equally revealing experience to be found outside the realm of science that should make readers realize that the scientific world is not so different from their own world. Indeed, science is an important, accessible, and empowering part of everyone's world.

In making comparisons and analogies with the uncertainties that exist in science and in everyday life, my goal is to help readers to understand and accommodate scientific uncertainty in much the same way that they deal with other uncertainties in life. I hope the reader will come away with the feeling that scientific uncertainty should cause no greater hesitation or doubt than do the multitude of other uncertainties that people regularly face and routinely accommodate in their lives. With a better understanding of scientific uncertainty, readers will be able to see through the clouds that sometimes obscure the value and relevance of science to societal issues. In the process of coming to understand uncertainty, they will become more self-confident in grasping what science can and cannot offer.

2 Uncertain about science

> This notion that "science" is something that belongs in a separate compartment of its own, apart from everyday life, is one that I should like to challenge. We live in a scientific age; yet we assume that knowledge is the prerogative of only a small number of human beings . . . . This is not true. The materials of science are the materials of life itself. Science is the reality of living, it is the what, the how, and the why in everything in our experience.
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> Rachel Carson, in accepting the 1952 National Book Award for *The Sea Around Us*

Science, as Rachel Carson observed, is a part of the very fabric of life. It has its strengths and weaknesses, its successes and failures, its doubts and uncertainties. As scientists attempt to understand how a cell malfunctions to produce cancer, how a gene transmits information to guide an organism's development, how an ecosystem responds to urban sprawl, or how the entire Earth responds to long-term changes in the chemistry of its atmosphere, these investigations are enveloped with uncertainty at every stage. The uncertainty arises in many ways, and the nature of the uncertainty may change through time, but the scientific endeavor is never free of uncertainty.

Has science been debilitated by uncertainty? To the contrary, the successes of science, and indeed there are many, arise from the ways that scientists have learned to make use of uncertainty in their quests for knowledge. Far from being an impediment that stalls science, uncertainty is a stimulus that propels science forward. Science thrives on uncertainty. The uncertainty of how genetic traits were replicated led eventually to discovery of the double helix molecular configuration. Indeed, one might argue that it is *certainty*, rather than uncertainty, that impedes science. The protracted struggle in the seventeenth century by Copernicus, Kepler, and Galileo to overturn the notion that Earth was at the center of the solar system[1] was carried

[1] This history is recounted more fully in Chapter 6.

on in the face of the then-prevalent theological certainty that Earth occupied a very special place in the architecture of the universe.

The uncertainties that scientists face are really not so different from the uncertainties we encounter in everyday life. Risk-taking is extolled in many cultures as an attribute of a successful person. But risk arises precisely because of uncertainty. The willingness and ability to formulate and take action and accept risk in the face of uncertainty is considered a character strength. To be sure, there are risks taken that later prove unwise, but without risk-taking there is an implicit acceptance of the *status quo*. An unwillingness to be motivated by uncertainty is indeed a real barrier to progress.

Ironically, people who are not scientists often equate science with certainty, rather than uncertainty. They have been conditioned by the highly precise and accurate predictions of eclipses, of the daily progression of ocean tides, of the exact times of the local sunrise and sunset, of the clockwork precision of a spacecraft landing on a distant planet. Another aspect of certainty relates to reliability of technology when people pick up the telephone, turn on the television, or turn the ignition key in an automobile, there is an expectation that the device will work. Indeed, when things do not happen as expected or as predicted, there usually is some measure of surprise and discontent. Most people do not relish surprises and are, at some level, uncomfortable with unpredictability and uncertainty.

Certainty in other contexts is a source of contentment. Religious tenets that assure the faithful an afterlife assuage concerns about the abyss of death. Some political mantras, such as 'smaller government is better government' or 'there is no such thing as a good tax', relieve those who recite them from the burden of evaluating a wide range of public policy issues. Recasting a world full of shades of gray into a simpler and starker entity comprising only blacks and whites eliminates the difficult task of weighing nuance and replaces it with the comfort that certainty offers.

When scientists cannot demonstrate a high level of certainty in their understanding of complex natural systems, there is sometimes

an undercurrent of impatience and discontent in the general public. In late 2001, bioterrorism in the form of anthrax spores appeared in government buildings and postal facilities in the USA. For a period of time, however, there was uncertainty and confusion in the public health community and at the National Center for Disease Control as to how exactly anthrax might be transmitted, what spore concentrations could be considered hazardous, and how anthrax spores could be rendered impotent. The public wanted answers that public health practitioners could not immediately provide. Similarly in the UK, an outbreak of foot and mouth disease in 2001 was met with a range of scientific opinion as to how it should be contained. Massive culling of neighboring herds was the containment strategy adopted, but scientific opinion was far from unanimous. Long after the disease waned, debate continued about whether the culling strategy was necessary or effective.

When scientists acknowledge that they do not know everything about a complex natural phenomenon such as the spread of disease through an ecosystem, the public sometimes translates that to mean that scientists do not know *anything* about the subject. That, in turn, leads to a loss of public credibility in the capabilities of the scientific community. A byproduct of the loss of credibility is an all-too-frequent willingness of the general public to entertain flimsy pronouncements from kooks, charlatans, and marginal skeptics. With an air of scientific authority and certainty, these pseudo-scientists make assertions that have never been subjected to the rigorous probing that is the foundation of genuine science.

Fortune-tellers, palm readers, clairvoyants, astrologers – the list could go on and on – all thrive on the inability or unwillingness of their clients to recognize the total lack of logical underpinnings and scientific observations in support of these practices. There is absolutely nothing that lends these charlatans any credence whatsoever. But their pronouncements are always carefully crafted to leave their clients with the impression that extraordinary powers have been objectively exercised. In the next chapter, I describe a particularly

egregious example of this, a prediction of a major earthquake that was taken far too seriously by far too many people who should have known better.

There are, of course, serious scholars who challenge the notion that science is the only pathway to universal truths. One school of philosophy, loosely referred to as postmodernism, questions whether scientists are neutral and objective, and whether scientific knowledge is truly the outcome of unbiased rational thought. In extreme form, it questions whether a deterministic natural world exists outside of the mental constructs that humans erect. This perspective from the fringe views science as a game with a set of rules created by scientists, and argues that the apparent successes of science in understanding the natural world would not be defensible if we did not accept the rules of the scientific game. A subtheme of this position is that science is a self-serving concept and entity.

In 1996, the postmodern perspective was brought into sharp focus, and ridicule, when Dr. Alan Sokal, a professor of physics at New York University, submitted an article[2] for publication to a journal known to espouse this particular philosophy. The contribution carried the title *Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity*, which seemed to convey a postmodern flavor. Because a physicist had submitted the manuscript, the editors of the journal welcomed the opportunity to publish an article by a scientist that seemed to erode the foundations of science from within. But the article by Sokal was a Trojan horse, a cleverly crafted hoax that illuminated not the philosophical frailty of the scientific method but rather the gullibility of the editors. Sokal had written a seemingly erudite essay, using convoluted language and structure, that really was nothing more than nonsense cloaked in pseudo-scientific jargon. The over-eager editors took the bait and published Sokal's article. Once it was in print, Sokal revealed the hoax. The implications of 'l'affaire Sokal', as it has been dubbed, are many, but for my purposes here the principal point is this: there are people,

[2]Alan D. Sokal, Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity, *Social Text*, 1996.

educated and not, who simply believe that science has nothing special to offer. They are skeptical of, or simply ignore, scientific results.

There is another type of person who may accept scientific results in general, except when the science conflicts with other beliefs they hold dearly. While writing this book, I read the obituary[3] of Charles K. Johnson, president of the International Flat Earth Research Society. Aside from this particular obsession about the shape of the planet, Mr. Johnson seemed to have led a rather normal life as an airplane mechanic. His disagreements with the scientific community were few, except as they related to the shape of the Earth. The image of the spherical Earth taken by the Apollo astronauts from the moon was easily explained: the moon landings were an elaborately staged hoax, and the photograph was but a prop in that scam. We may smile at this quaint explanation, but the pool of uncertainty about science is deepened, little by little, by each and every Charles Johnson who successfully draws attention to his particular astigmatic view of the natural world. In 1994, a poll[4] showed that almost one in ten Americans thought the moon landings were faked. And Hollywood does not help matters with creations such as the 1998 film 'Wag the Dog', in which a US President seeks to divert attention away from personal impropriety by manufacturing a fake war against Albania, including a staged invasion with faked film footage depicting destruction and carnage.

A more widely known conflict between science and personal belief centers on the biblical account of creation in the Book of Genesis. The issue is whether the bible is literally true, word by word. Did God create the entire universe and every living creature in just six days? Geologists and evolutionary biologists make a persuasive case that not all modern life forms were present at the birthday of Earth, and that most of today's life has evolved from other life forms over the vast expanse of geologic time. But biblical literalists do not accept an iota of departure from the Book of Genesis. If Genesis is literally correct, then modern geology and biology must be wrong.

[3] *New York Times*, 25 March 2001. [4] Marc Fisher, *Washington Post*, 20 July 1994.

Creationists have now taken on the task of proving the tenets of evolutionary biology incorrect, through an endeavor they identify as 'creation science'. The so-called creation scientists have tried to identify flaws in the logic or observations of evolutionary biology so as to 'disprove' it. They have not, however, applied equal vigor to testing the hypothesis set forth in the Book of Genesis. They will not even acknowledge that the account in Genesis is even an hypothesis, let alone testable. They can conceive of no experiment, no observation, that might disprove Genesis. Therein lies the reason that the practitioners of 'creation science' are not really scientists. Creationists will never concede their fundamental position, that all living things are the direct and simultaneous creations of a supreme being. They cannot permit themselves to admit the possibility that the biblical account of creation might not be true or may someday be shown to be untenable. Practitioners of genuine science, by contrast, easily admit uncertainty and are very comfortable working in an uncertain environment. In real science, few concepts can ever be accepted as unquestionably true or absolutely certain.

Indeed, genuine science operates on the assumption that a concept *can* be shown to be false. Falsification occurs when a concept is shown to be logically inconsistent or runs counter to direct observations. Lynton Caldwell, in a review of Michael Zimmerman's book *Science, Non-Science, and Nonsense*[5], describes science as a process of "separating the demonstrably false from the probably true".[6] It is a fundamental underpinning of science that only falsehoods, not truths, can be proven. Truths are simply the survivors of multiple attempts at undercutting. In fact, science progresses in part by continually probing for the soft underbelly of concepts that may have some partial success in explaining some natural phenomena. The unending search for weaknesses may reveal subtle inconsistencies that ultimately require revision or rejection of the original concept.

[5]Johns Hopkins University Press, Baltimore, MD, 1995.
[6]*The Environment*, vol. 38, n. 6, p. 25, 1996.