

UNCERTAINTY AND TOLERANCE IN SCIENCE AND DECISIONMAKING

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John H. Gibbons has outlined the problem of decisionmaking in the face of uncertainty regarding human-exacerbated, global climatic change.¹ The present status of knowledge seems sufficient for caution but insufficient to justify definitive action, especially when the action may also have uncertain consequences of great economic impact. It is this problem of scientific knowledge as a basis for action that I wish to discuss.

My perspective is that of a geologist. In the public mind geologists are commonly associated with the production of oil, gas, coal, and other industrial contributions to global environmental change. The association is unfortunate because geology is the study of the Earth, not its exploitation. As do all real scientists, geologists have a special feeling about that which they study.² It is from this feeling about the Earth that they discover new things.

I should admit at the outset that I am a rather strange kind of geologist. In every scientific discipline, forces move practitioners to the core of their discipline. Publication opportunities, citation of works by peers, favorable reviews of research proposals, and similar benefits accrue to those at a discipline's core. Somehow my natural inclinations and chance have propelled my work to the fringe of geology. Rewards are less certain at the fringe, but the chance of discovery is greatest in this realm of uncertainty.

The concept of certainty strikes me as very interesting, not so much in my own work as in human psychology and sociology. I emphasize certainty here because I think people expect a kind of certainty from science when they talk about reducing uncertainties. Nonetheless, there is a major difference between this public perception and how we scientists understand uncertainty in nature. As a scientist, I find a tremendous joy in uncertainty. Without it I would have nothing to do. Uncertainty offers tremendous opportunity, because it means that the things we do can make a difference. This is only possible when future outcomes do not necessarily follow from present conditions. If the world were certain we would all have to be fatalistic, since nothing that we could do would matter. One can even say that one of the fundamental opportunities of being human is the opportunity of uncertainty.

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1. The keynote paper for which I am a discussant is John Gibbons, *Decisionmaking in the Face of Uncertainty* (elsewhere in this issue—Eds.).

2. The feeling of scientists for that which they study was well exemplified by geneticist Barbara McClintock, as described by Evelyn F. Keller, *A Feeling for the Organism* (1983).

However, as with most things in nature, we can also conceive a dark side to uncertainty.

I suggest that public concern over uncertainty has to do with something called *fear*. Fear is not something that physical scientists consider very much, but it lies at the origin of all science. It was in their attempt to cope with a fearful environment that human beings stumbled on the process of science. Although there is considerable disagreement on what science is or even if it is possible to define science, most historians agree that science, at least in Western cultures, had two births. The first of these died about the time of Socrates.³ The second birth of science arose in the 1500s and continues to the present.

During the first scientific era in ancient Greece, scientists were few, and people did not turn to them to resolve problems of impending doom. Instead, they consulted oracles. Perhaps the most famous incident involved the ancient Athenians, inventors of democracy. Athens, a city state of a few tens of thousands citizens, was threatened by an immense array of Persian forces led by Xerxes. Athens sent envoys to Delphi, the oracle of Apollo, the god who embodied truth. However, truth was then, as now, an elusive, paradoxical commodity. The ancient philosopher Heraclitus expressed this with his famous observation: "The lord whose oracle is in Delphi neither speaks out nor conceals, but gives a sign."⁴

Those who seek certainty in the modern world no longer consult oracles. Now it is the scientific technical community that is called upon to speak truth, to dispel fear, to provide certainty. Of course, the process is quite different than when a priestess became intoxicated by volcanic fumes. Geologists also are inspired by nature but by a process that is presumably better informed than the ancient one.

The Priestess Aristonice at Delphi revealed an enigmatic prophecy in two parts.⁵ The first part foretold doom and destruction. The second part, responding to the resulting despair of the envoys, provided this ray of hope: "[T]he wooden wall only shall not fall, but help you and your children." Two different courses of action were based upon this prophecy. One large band of Athenians barricaded the Acropolis with planks and timbers. Xerxes's army subsequently overran this wooden wall, butchered all within, and destroyed the Acropolis by fire. Another action based on the divined truth was implemented by Themistocles, leader of the unified Greek forces. At Salamis the Greek fleet defeated that of Xerxes. A wooden wall of ships

3. The richness of pre-Socratic science is described by B. Farrington, *Greek Science* (1961) and Carl Sagan, *Cosmos* (1980).

4. Quoted as a fragment of Heraclitus' philosophy by Plutarch, as described by G.S. Kirk, J. E. Raven & M. Schofield, *The Presocratic Philosophers: A Critical History with a Selection of Texts* 209(1983).

5. The incident at Delphi and subsequent actions are related by Herodotus, *The Histories* 461 (1954).

preserved not only Greece but all subsequent western civilization, the entire heritage of our modern culture.

As in ancient times, we still face an uncertain future. Great catastrophes are always possible. My own scientific work concentrates on catastrophic floods. This past July I did field work in the Gorno Altay region of south-central Siberia. Great catastrophic floods during the last Ice Age effected immense change on the headwaters of the Ob River. Flood water moving 10 to 20 meters per second created giant gravel bars up to 200 meters high. Such floods remind us that the Earth is a very uncertain place, and over long time scales great catastrophes become likely.

An interesting discovery of our modern scientific era is that of mechanical processes involving energy and time. The quotient of energy and time is power, which was supplied in abundance when ice-dammed glacial lakes released their waters during the ice-age Siberian floods noted above.⁶ We are able to understand such processes because of a habit of nature that we call the conservation of energy. In the former Soviet Union, they ascribed the discovery of this great principle to one of history's greatest scientists, Mikhail Vasilievich Lomonosov (1711-1765). In a 1748 letter to the mathematician Euler, Lomonosov formulated conservation principles applicable to matter and motion, the product of which provides one measure of energy.⁷ Lomonosov was elevated to heroic status by the communist leaders of the Soviet Union. Stalin had Lomonosov's statue placed in front of the prestigious Moscow State University. The glorified scientist had become the source of state certainty.

Even the dictionary definitions of science perpetuate a myth of certainty: "science...a branch of knowledge or study dealing with a body of facts or truths systematically arranged and showing the operation of general laws."⁸ Such views, which I regret many scientists hold, are very scary because certainty, like uncertainty, also has a dark side.

There is a place where many scholars would suggest that the modern era of science, a renewal of ancient Greek traditions, was reborn. In Krakow, Poland, a cleric named Copernicus set in motion the scientific enlightenment with his transformation of the prevailing Earth-centered cosmos to our present world view of the solar system responding with certainty to scientific laws.⁹ However, only 50 kilometers west of Krakow lies a monument to certainty's horror. A dreary group of stone buildings near the town of

6. The power of glacial floods is described by Victor R. Baker & John E. Costa, *Flood Power*, in *Catastrophic Flooding 1* (L. Mayer & ID. Nash eds., 1987).

7. Lomonosov's accomplishments are described by G. Pavlova & A. Federov, *Mikhail Vasilievich Lomonosov: His Life and Work* (1984).

8. *The American College Dictionary* 1086 (C. Barnhart ed., 1960).

9. This so-called "Copernican Revolution" is the type example for the relativist view of science erected by Thomas Kuhn in contrast to the then prevailing rationalist views. See Thomas S. Kuhn, *The Structure of Scientific Revolutions* (1962).

Oswiecim has an ironwork entrance gate, adorned with the sign that proclaims "Arbeit Macht Frei." Better known by its German name Auschwitz, it is a place where people became numbers, and, with the justification of absolute certainty, the number four million was extinguished, as in some mechanical calculation. Science does not provide absolute certainty and never will. Its "truths", unlike those of perpetrators of Auschwitz, must always be tested against reality.¹⁰

Whereas certainty conveys great power, absolute power (or certainty) is unacceptable. The balance provided by uncertainty leads to what Jacob Bronowski calls tolerance.¹¹ He envisions Heisenberg's famous Uncertainty Principle of quantum mechanics renamed the Tolerance Principle.¹² Bronowski also cites the English mathematician William Clifford for a definition of scientific truth.

Remember, then, that scientific thought is the guide of action; that the truth at which it arrives is not that which we can ideally contemplate without error, but that which we may act upon without fear; and you cannot fail to see that scientific thought is not an accompaniment or condition of human progress, but human progress itself.¹³

Too often science is merely equated with its theories, which, Clifford notes, seek to "ideally contemplate without error." These do not constitute scientific truth, which is "that which we may act upon without fear." Here then is the challenge for decisionmaking. In meeting it we cannot view science as a separate enterprise, what Clifford calls "an accompaniment or condition of human progress." Scientific thought is "human progress itself." To avoid intolerance, or dogma, the intimate connection of scientist and decisionmaker in scientific thought must be facilitated.

Like the oracles of old, science can be viewed with detachment, as a source of revelation. By ascribing absolute truth to its predictions one achieves a vision of immense power for decisionmaking. Commonsense dictates caution, a Principle of Tolerance. Catastrophes are associated with immense power. The view that scientific thoughts are not just in some detached group of scientists but that we are all in scientific thought is not easily grasped.¹⁴ The view does not derive from ideal logic. Rather, it comes from the pragmatic perception that only in this way will we find that which we may

10. The critical rationalist, in contrast to the scientific relativist, argues that the core of science lies in falsification. Hypotheses can never be proven, only falsified. These ideas are well developed by Karl R. Popper, *The Logic of Scientific Discovery* (1972).

11. J. Bronowsky, *The Common Sense of Science* 67-68 (1978).

12. J. Bronowsky, *The Ascent of Man* 365 (1973).

13. Bronowsky, *supra* note 11, at 128 (citing William Clifford, *The Common Sense of the Exact Sciences* (n.d.)).

14. The American philosopher Charles Sanders Peirce (1839-1914) provided the most cogent expression of this view. See, Charles Peirce, *Collected Papers* (C. Hartshorne & P. Weiss, eds., 1931-58).

act upon without fear.

What can such philosophy contribute to the issue of policy-making with regard to global change? Public perception, so important for compelling political action, was galvanized on this issue by the June 23, 1988 testimony¹⁵ to the United States Senate by Dr. James Hansen of the National Aeronautics and Space Administration Goddard Institute of Space Studies. Dr. Hansen's testimony conceptualized, in conventional scientific fashion, the highly probable causative link between well-documented greenhouse gas increases and recent warming trends in globally averaged temperature records. Given the probable continuance of these trends, Hansen observed that the most likely result would be an increase in the occurrence of heat waves and droughts of the types occurring in the summer of 1988. The concepts of probability and causation, which Dr. Hansen carefully stated in his remarks to the Senate, were not included with the national media's subsequent perception that a scientist was claiming that global warming was the cause for drought.¹⁶ This muddling of concepts and percepts has spilled into the scientific arena and inspired some scientists to advocate immediate societal action on global warming issues.¹⁷ Others claim, however, that delays in action to reduce greenhouse gases pose small penalties but increase the information on which to base future decisions.¹⁸

This predicament poses a dilemma that the following quip, attributed to the philosopher Immanuel Kant, expressed two centuries ago: "Concepts without percepts are empty; percepts without concepts are blind."¹⁹ Value-dominated percepts, not science-dominated concepts, compel action. Science provides the vision for otherwise blind, percept-based action. A linkage must be present between what people care about (percepts, such as human health, economy and environmental quality) and what science can predict or detect (concepts, such as greenhouse gases and temperature records).²⁰ This

15. James Hansen, (Comm. on Energy and Nat. Resources, U.S. Senate), *The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves*, in *Greenhouse Effect and Global Climate Change* 42 (1988).

16. Stephen H. Schneider, *Global Warming: Is It Real and Should It Be Part of a Global Change Program*, in *Global Change & Our Common Future* 209 (R.S. DeFries & T.F. Malone, eds., 1989)

17. James S. Risbey, Mark D. Handel & Peter K. Stone, *Should We Delay Responses to the Greenhouse Issue?*, 72 EOS 593 (1991); James S. Risbey, Mark D. Handel & Peter K. Stone, *Do We Know What Difference a Delay Makes?*, 72 EOS 596 (1991).

18. Michael E. Schlesinger & Xingjian Jiang, *Revised Projection of Future Greenhouse Warming*, 350 Nature 219 (1991); Michael E. Schlesinger & Xingjian Jiang, *A Phased in Approach to Greenhouse-Gas-Induced Climatic Change*, 72 EOS 593, 596 (1991); Schlesinger & Jiang, *Climatic Responses to Increasing Greenhouse Gases*, 72 EOS 597 (1991).

19. The epistemology and metaphysics of this view are presented by Immanuel Kant, *Critique of Pure Reason* (1787). A similar view was expressed by the physicist Albert Einstein, *The World as I See It* (1934) ("Science without religion is lame, religion without science is blind.").

20. Robert Mendelsohn, Book Review, 79 Am. Sci. 177(1991) (reviewing Derek Ellis, *Environments at Risk*).

linkage can occur only as a balance in which value-laden percepts and science-laden concepts are part of the same process. This is not a process in which decisions are based solely on concepts, while bemoaning the irrational influence of percepts. Rather, in the spirit of Clifford's advice, science should serve as the guide to the actions that follow from percept-based decisions. The whole process of action will then reside within a continuity of scientific thought.

How do we overcome the prevailing percept that action must be based on concepts shown with absolute certainty to be correct, or as Clifford states, "that which we can ideally contemplate without error"? As modern T-Shirts proclaim: "Just Do It!" The immediate action can be whatever society conceives to be in its best interest. Science does not exist to provide absolute knowledge on which to base this action since such knowledge can be achieved only in infinite time. Moreover, were such absolute knowledge ever achieved, science would cease to exist.

The important principle is that actions continuously be subject to scientific criticism and guidance. The consequences of actions inform scientific theories with their tests of reality. To achieve such action within a context of scientific thought, the prevailing percept of uncertainty as a horror to be avoided will need to be transformed to one of tolerance as an opportunity for enlightened change. Tolerance is necessary for concerned scientists like Dr. Hansen to present publicly their best model results indicating future trends. If trends indicate the possibility of large-scale disaster and if societal values are consistent with proposed action, there is no need to wait for the confirmed reality of that disaster. However, the principle of tolerance also dictates that the action be continually assessed and subject to modification as its implementation reveals whether it is as prudent as originally hypothesized. As observed by the late Mohandas K. Gandhi: "Life is an endless series of experiments."²¹



21. Joan McIntosh, *Explorations: A Journal of Possibilities* 57 (1990)