Turning Numbers into Knowledge

MASTERING THE ART OF PROBLEM SOLVING

Second Edition

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Analytics Press
PO Box 20313
Oakland, CA 94620-0313
http://www.analyticspress.com
http://www.numbersintoknowledge.com

CHAPTER

4

PEER REVIEW AND SCIENTIFIC DISCOVERY

Science is a human process that advances in fits and starts. The end result of this process is generally something you can count on, but the intermediate steps to this result do not advance in a linear progression as science textbooks might lead you to believe (see Kuhn's *Structure of Scientific Revolutions*). Understanding the process by which scientific knowledge is created can help you better assess its implications and relevance to your own analysis.

Most people (especially nonscientists) don't recognize the large role that intuition and instinct play in scientific discovery, particularly in the process of developing hypotheses. A scientist's desires for recognition and status, enthusiasm for solving a problem, and attitudes towards authority are all motivations rooted in human needs and emotions.

These human inclinations all affect the progress of science, but the end result of the scientific process is one that is rational to the core. Science has an internal coherence and predictive power that is unique among human endeavors. Historian of science Gerald Holton identifies the "apparent contradiction between the seemingly illogical nature of actual personal discovery and the logical nature of well-developed scientific concepts."[17]

This stark contrast between the messy business of scientific discovery and the end result, which is the most accurate description possible of how the physical world operates given current knowledge, comes about in part because of a process known as "peer review." It is important for nonscientists to understand how this process works, because accurate peer review, more than any other part of the scientific process, determines whether a particular set of research results is credible. For a detailed look at peer review, go to <http://en.wikipedia.org/wiki/peer_review>.

THE IMPORTANCE OF PEER REVIEW

The formal process of peer review is most often conducted for articles submitted to scholarly ("peer-reviewed") journals or for research proposals submitted to funding agencies (such as the National Science Foundation). In journal reviews, the author submits the article to the editor, who then distributes the article to between one and four reviewers. The reviews are sometimes "blind" so that the reviewers don't know the names of the authors and their affiliations (it is however often possible for knowledgeable reviewers to infer the identities of the authors from a paper's citations and the authors' approach in presenting the results). More often, the authors' names are known to the reviewer. Only rarely is the *reviewer's* name revealed to the authors when comments are delivered. Both the number of reviewers and whether the reviews are blind are at the discretion of the journal editor.

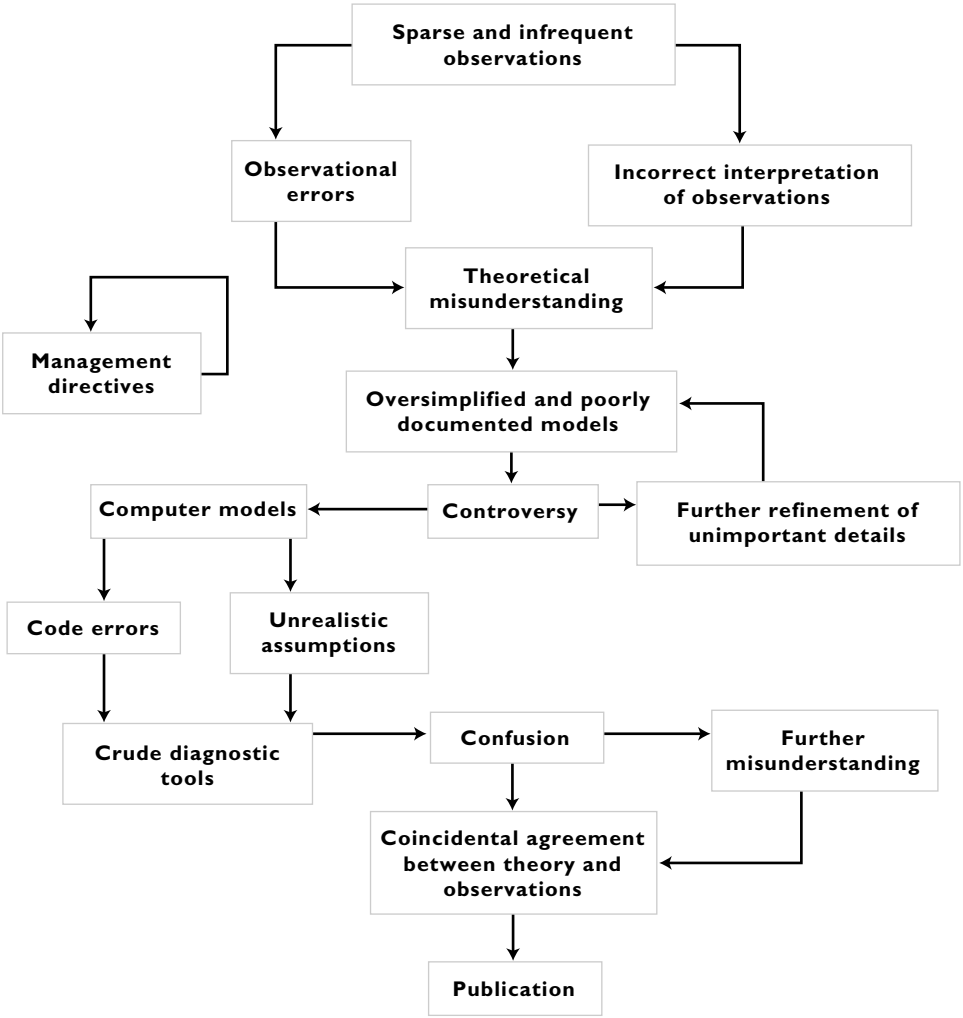
Reviews of scientific project proposals are usually more formalized than are journal reviews as befits a process upon which research funding depends directly. In addition, some journals and most funding agencies require researchers to declare any potential conflicts of interest before the review process begins.

The purpose of peer review is to judge whether the work is based on principles and judgments that represent the current scientific consensus. When such a consensus exists in a particular field, it reflects the paradigm accepted by scientists in that field and gives practitioners a standard set of tools with which to evaluate new ideas (see Kuhn's *Structure of Scientific Revolutions* for more details). When a paradigm is challenged by anomalous observations and experiments, a crisis ensues. The crisis continues until a new paradigm emerges that encompasses the anomalous results. During periods of crisis (or in non-scientific fields) peer review is generally less reliable because the foundations upon which the reviewers judge research results in the field are being questioned in fundamental ways.

Adequate documentation is a pillar of the peer review process. Without it, scientists could not verify or reproduce results, and scientific progress would grind to a halt. The best scientists are fanatical about documentation and you should be also.

Peer review does not guarantee accuracy. In fact, papers containing major scientific blunders have been published in peer-reviewed journals.[18] However, the formal peer review process makes it more likely that a paper will avoid major flaws. Be skeptical of "research" results that are not peer reviewed. There are some "scientists" who announce their results to the media but do not publish

FIGURE 4.1. A comical view of how human frailty can affect the course of science[19]



in peer-reviewed journals. Usually, such announcements are funded by particular organizations with an ax to grind and have little to do with science.

The "cold fusion" episode in 1989 is one example where the announcement of a "discovery" in a press conference but not in the refereed literature led to a media circus. Two scientists at the University of Utah (Martin Fleischmann and Stan Pons) claimed that they had created a room-temperature process that generated significantly more energy than it took to run the experiment, and that they had detected evidence that a nuclear fusion reaction was responsible. Had

the press been more skeptical of a research result announced only in a press conference, its pronouncements might have been more cautious. Instead, the claim of limitless cheap energy resounded loudly around the world, only to fall to the ground with a sickening "thud" when experiments by other scientists failed to corroborate the results.

How can you tell if a scientific study has been peer reviewed? **Table 4.1** lists some important peer-reviewed journals for key scientific fields. If the study is published in one of these journals, it's passed the first hurdle of basic scientific credibility. For a long (but still probably incomplete) list of peer-reviewed journals, check out <http://adswww.harvard.edu/abs_doc/refereed.html>. For a ranking of the importance of different journals in virtually all scientific fields, see the *Science Citation Index*, put out annually by the Institute for Scientific Information or ISI <http://www.isinet.com>. These rankings are based on the number of citations to papers in a given journal by the scientists in that field, so they are a relatively objective measure of journal quality (although no index is perfect and this one is no exception, as Wikipedia points out: <http://en.wikipedia.org/wiki/impact_factor>). In its electronic database, ISI's web site also has a large searchable list of journals, as well as other related products.

SCIENTIFIC PROOF

There are two kinds of proof accepted in scientific research. The first, based on deductive logic, relies on assumptions and general principles to derive implications and predictions of specific events.[20] If I leave my bicycle outside and it rains, I deduce from my experience and the laws of chemistry that parts of the bicycle will rust. Deductive inferences rely on a set of initial assumptions ("axioms"), which are analyzed using rules of logic. If the initial assumptions are correct, the rules of logic are followed, and no logical contradictions arise in the analysis, then the conclusions must be correct.

The second kind of proof–inductive logic, on which many inferences in science and other forms of human endeavors are based–relies on compilations of specific instances to infer general laws from the specifics (see Hughes, *Critical Thinking*). If I leave my bicycle unlocked outside for a hundred days and it is never stolen, I could use inductive logic to infer that it will not be stolen tomorrow, but I cannot be sure. I can only say that it is *unlikely* to be stolen, based on

TABLE 4.1. Some important peer-reviewed scientific journals

Field	*Journal*
Basic Science/Medicine	Science Nature Cell Nature Medicine
Clinical Medicine	New England Journal of Medicine Journal of the American Medical Association Annals of Internal Medicine
Physics	Physical Review Physical Review Letters Nature
Chemistry	Science Accounts of Chemical Research Journal of the American Chemical Society
Physical Chemistry	Journal of Physical Chemistry Journal of Chemical Physics Chemical Physics Letters
Biology	Science Nature
Geology/Geophysics	Journal of Geophysical Research — Solid Earth Geophysics Applied Geophysics
Global climate	Global Biogeochemical Cycles Tellus Biogeochemistry
Ecology	Ecology Ecological Applications
General Environmental Science	Environmental Science and Technology Atmospheric Environment
Hydrology	Water Resources Research Journal of Contaminant Hydrology
Combustion Technologies	Combustion and Flame Combustion Science and Technology
Electrochemical Technologies	Industrial Engineering & Chemical Research Journal of Power Sources Journal of Electrochemical Society
Physical Chemistry Technologies	Applied Surface Science Journal of Non-Crystalline Solids Applied Spectroscopy
Biological Technologies	Methods in Enzymology Biochemical Pharmacology American Journal of Physiology

my extrapolation of past experience. Inductive proof is less certain than deductive proof (in rare instances it can be *as* certain, but never more so).

The *Encyclopedia of Philosophy* defines inductive argument to include "all cases of nondemonstrative argument, in which the truth of the premises, while not entailing the truth of the conclusion, purports to be a good reason for belief in it."[21] In plain English, an inductive proof shows that the conclusion is highly probable but not demonstrably true in the same way that a correct deductive proof is. Induction is the link between mathematics, deductive logic, and our experience of the physical world.

Deduction by itself is impotent because it depends only on assumptions and its own internal logic. Without induction to enrich the set of data and assumptions upon which deductions can be based, the world of deduction would be a spare one, indeed. When inductive logic was first formalized, the goal of its devotees was to show that its results were demonstrably *true*, in the same way conclusions based on deductive logic were true. According to the *Encyclopedia of Philosophy,* "not until the end of the 19th Century did a more modest conception of inductive argument and scientific method, directed toward acquiring probability rather than certainty, begin to prevail." [22]

The limitations of induction are offset in part by the peer review process. Outside reviewers uncover errors of fact, logic, and omission, and report them to the authors and the journal. Obvious errors are weeded out quickly while more fundamental flaws may take years, decades, or even centuries to be uncovered. Eventually, though, even these errors will be discovered as scientists attempt to build on previous work. Serious flaws will result in logical inconsistencies (discovered through deduction) that will inevitably surface and be corrected.

THE SCIENTIFIC OUTLOOK

The physicist Alan Sokal points out that science is predicated on two key attitudes:

- being willing to accept what you find; and
- being willing to discover that you are wrong.

Human nature being what it is, these two attitudes are rare. Next time you find

yourself resisting a new idea, take a deep breath and try to see the other point of view. Ask yourself why this idea might make you uncomfortable (often it's
5 because it clashes with your ideology). If you can step back from a situation in this way, you will have achieved what I like to call the true "scientific outlook."

CONCLUSIONS

Science and technology are a critical part of modern life. You owe it to yourself to understand at least the basics of how scientific knowledge is created and used.

Remember always that science is a human endeavor. Learn about the process so you can better appreciate how to interpret scientific findings. Finally, always give more weight to peer-reviewed research than to results announced solely in the media.

EXERCISE

Find a newspaper story summarizing a scientific study that interests you. Find out where the author of the study works. Who funded the research? What's the name of the journal in which the research was originally published? Is it a refereed journal? Send for the report and compare it to the newspaper article's summary of its conclusions. Is the newspaper summary accurate?

The supreme task . . . is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical path to these laws; only intuition, resting on sympathetic understanding of experience, can reach them. — **ALBERT EINSTEIN**