WHAT MAINTAINS THE INTEGRITY OF SCIENCE: AN ESSAY FOR NONSCIENTISTS

Katherine L. Gross[*]
Gary G. Mittelbach[**]

> *"And all this science I don't understand. It's just my job five days a week."*
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> —*Rocket Man*, Elton John & Bernie Taupin

INTRODUCTION

Science shapes our everyday world, yet we rarely think about how it is done, or more appropriately for this Symposium, what processes are used by scientists and "consumers of science" to distinguish valid science from invalid science. Valid science is what should be taught in the classroom (e.g., the teaching of evolution instead of intelligent design),[1] what should be used to determine consumer safety,[2] and what should be used in a court of law. Science is not static; it is a process. It progresses as new evidence is accumulated, as hypotheses are tested and rejected, and as new technologies emerge to allow collection and evaluation of data in new ways. Scientists can, and do, debate what constitutes "good evidence," especially when a well-

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[*] Department of Plant Biology and WK Kellogg Biological Station, Michigan State University, Hickory Corners, MI 49060, kgross@kbs.msu.edu.

[**] Department of Zoology and WK Kellogg Biological Station, Michigan State University, Hickory Corners, MI 49060, mittelbach@kbs.msu.edu.

Dr. Francesca Grifo of the Union of Concerned Scientists, was scheduled to speak in this Symposium on the subject of scientific integrity, but had to decline due to a sudden illness. We regret that Dr. Grifo was unable to give her presentation and we hope that we have covered some of the topics that she would have included in her essay. We thank our son, John Mittelbach, the Editor in Chief for volume 57 of this Journal and a co-organizer of this Symposium, for the (also sudden) invitation to fill in for Dr. Grifo, and for having the confidence that we would not embarrass him. We thank the Thrower family, Emory Law, the students of the *Emory Law Journal*, and the speakers in this Symposium for an outstanding event and for a stimulating exchange of ideas. Finally, we acknowledge our colleagues—faculty, students, and post-docs—with whom we have discussed these ideas throughout our careers and who have helped shape our understanding of the factors that maintain scientific integrity.

[1] *See generally* DAVID SLOAN WILSON, EVOLUTION FOR EVERYONE: HOW DARWIN'S THEORY CAN CHANGE THE WAY WE THINK ABOUT OUR LIVES (2007).

[2] *See* Thomas O. McGarity, *Corporate Accountability for Scientific Fraud: Ketek and the Perils of Aggressive Agency Preemption*, 58 EMORY L.J. 287 (2008).

established hypothesis is challenged or a new discovery is made. To a layperson, this process of scientific scrutiny may appear bewildering and potentially open to manipulation, especially when complex statistics or apparently contradictory evidence is involved.[3]

Legal science, the theme of this Symposium, addresses the interplay between science and the law. Increasingly, the legal system relies on the discoveries and validity of basic science in the evaluation of evidence. The most dramatic example of this is the revolution in evidence gathering and interpretation brought about by the contributions of molecular biology and DNA analysis.[4] Although DNA testing is solidly in the mainstream of legal science, other scientific applications, such as the use of brain scans employing functional magnetic resonance imaging (fMRI) to assess truthfulness in witness testimony, are highly controversial.[5] Judges and juries are expected to determine the truthfulness of testimony presented by a witness or an expert, which is difficult when the experts disagree as to the validity of scientific evidence. Further, judges are now required to evaluate scientific expertise and the validity of the experts who present evidence or arguments in court.[6]

What distinguishes "good science" from "bad science" or "pseudoscience," and how do scientists and society prevent the misuse of science? These are challenging questions and a lengthy discussion of these issues is beyond the scope of this Essay. Our goal is more modest. Here we attempt to outline for nonscientists (the majority of readers of this Journal) some of the mechanisms that serve to maintain the integrity of science. In doing so, we hope to shed some light on the scientific process and how it functions to maintain the integrity of science. We begin with a brief overview of the scientific method and then discuss four components of the scientific process that are central to maintaining the integrity of science. These are (1) repeatability, (2) open communication (data sharing), (3) objective interpretation (statistical inference), and (4) peer review. While individual scientists may argue (scientists, like lawyers, enjoy a good debate) about the relative importance of

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[3] One prominent and timely example is the debate regarding scientific findings concerning global climate change. *See, e.g.*, William H. Schlesinger, *An Ecologist's Thoughts on Forests and Farms in a Cap-and-Trade System*, 58 EMORY L.J. 423 (2008) (discussing global climate change and potential problems with cap-and-trade systems as a control mechanism).

[4] This development was highlighted by Professor Jennifer Mnookin in her Symposium presentation.

[5] *See* Julie A. Seaman, *Black Boxes*, 58 EMORY L.J. 427 (2008).

[6] *See, e.g.*, Daubert v. Merrell Dow Pharm., Inc., 509 U.S. 579 (1993).

these components for maintaining the integrity of science, all would agree that they are critical to the process.

I. THE SCIENTIFIC METHOD

The scientific method is the foundation of science. It is the process by which scientists develop knowledge of the natural world. It is so central to the conduct of science that the Supreme Court specified the use of the scientific method as one of the criteria for judging the reliability of expert scientific testimony.[7] Although we all may have learned the basics of the scientific method in elementary or secondary school science classes, a quick refresher is useful here.

The scientific method, in a nutshell, works as follows. Develop a hypothesis (an idea) of how the natural world works, devise an experiment or observation that will test the prediction(s) of this hypothesis, conduct an experiment or make an observation to test the prediction(s), and analyze the data collected. If the data fail to match the prediction, reject the hypothesis. If the data match the prediction, tentatively accept the hypothesis as true. Continue to refine the hypothesis and repeat the process. Ideas that stand up to repeated testing by the scientific method become the working knowledge of science and may even become its accepted "laws." Note, however, that even scientific laws can be overturned by new data. Thus, while science is progressive, it can only increase our confidence in a theory of nature—it can never prove that a theory or hypothesis is true. It is also inclusive. New data that are not consistent with a longstanding hypothesis or law will cause scientists to revise or develop a new law. But the new law has to include the observations that were used to uphold the previous law.[8]

The scientific method, as a process, works to maintain the integrity of science because each new observation or result is subject to repeated testing and scrutiny. Thus, scientists themselves bear a high responsibility for maintaining the integrity of science—their work is expected to be honest and open to review and repeated testing. This can (and often does) require that data from their experiments be made available and that their experimental methods be described in sufficient detail for others to repeat the study. Unlike

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[7] *See id.* at 590.

[8] *See* ROBERT M. HAZEN & JAMES TREFIL, SCIENCE MATTERS: ACHIEVING SCIENTIFIC LITERACY 14–15 (1991).

many other endeavors, there are few regulations that govern the conduct of science, outside of those that govern research with human subjects and animals, conflicts of interest, and gross misconduct. The integrity of science thus relies on the integrity—and skepticism—of scientists. As Robert MacArthur, a pioneer in ecology, once noted, "The only rules of scientific method are honest observations and accurate logic."[9] But what prevents scientists from being dishonest in their observations, or inaccurate in their logic?

Early in the seventeenth century, when the groundwork for modern scientific publication was developed by Robert Boyle and his colleagues at the Royal Society of London, the number of practicing scientists was small, so the trustworthiness and reputation of the individual scientist reporting the outcome of an experiment or natural history observation was critical to its acceptance.[10] Today the sheer size of the scientific community and its global distribution make it impossible to know many of science's practitioners personally. Moreover, the integrity of science cannot rely simply on the trustworthiness of researchers, for two important reasons. First, scientists are human. As such, they are subject to the failings of ambition, vanity, and greed, as well as the external influences of culture and politics. Second, even the best-intentioned scientists can get so caught up in their own worldview that they cling to a favorite hypothesis or refuse to accept observations that are inconsistent with their view.

If science is largely self-regulating and scientists are human, what maintains scientific integrity? As we noted above, there are four fundamental principles that guard the conduct of science and promote or maintain the integrity of scientific endeavors: (1) repeatability of observations and replication of results, (2) open communication and the sharing of data, (3) objective interpretation of the evidence, and (4) peer review. We discuss each of these below.

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[9] ROBERT H. MACARTHUR, GEOGRAPHICAL ECOLOGY: PATTERNS IN THE DISTRIBUTION OF SPECIES 1 (Princeton Univ. Press 1984) (1972).

[10] *See* STEVEN SHAPIN, A SOCIAL HISTORY OF TRUTH: CIVILITY AND SCIENCE IN SEVENTEENTH-CENTURY ENGLAND 126–93 (1994); Mildred K. Cho et al., *Lessons of the Stem Cell Scandal*, 311 SCIENCE 614 (2006).

A. Repeatability of Observations and Replication of Results

The ability to repeat an experiment and thereby to confirm (or reject) a finding is central to the scientific method and to maintaining scientific integrity. Any discovery, no matter how exciting, is suspect until it has been confirmed. A good example is cold fusion. In 1989, two researchers from the University of Utah announced the startling discovery that they were able to produce a nuclear fusion reaction at room temperature.[11] Not surprisingly, the potential for cold fusion to produce an abundant source of energy and free us from reliance on fossil fuels attracted a great deal of attention. Unfortunately, researchers from other labs were unable to repeat the initial results, and as a consequence, the phenomenon of cold fusion was quickly called into question. After two review panels, the U.S. Department of Energy decided in 2004 not to recommend a federally funded program focused on cold fusion.[12] Controversy over cold fusion continues in some camps, but the inability of scientists to replicate key results, coupled with the lack of theoretical explanation for the process, led to its abandonment by mainstream physics.

A more recent example of the inability to repeat key observations was the apparent breakthrough in stem-cell research by a South Korean scientist showing somatic cell nuclear transfer (SCNT). Although the results were published in the prestigious peer-reviewed journal *Science*,[13] concerns about the work's validity soon emerged. Ultimately it was shown that the original study was largely a product of fraud.[14] This example shows that while components of the process that maintain scientific integrity may fail (in this case, the peer-review system), the overall process still works. Even though scientific "peers" initially recommended that the work be published, the attention that the work received and the efforts to duplicate its findings soon revealed the fraud.

To meet the criteria of repeatability, scientists must report both the results of their experiments and the methods used to conduct their work and gather the data. How frequently experiments are actually repeated varies widely by

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[11] Martin Fleischmann & Stanley Pons, *Electrochemically Induced Nuclear Fusion of Deuterium*, 261 J. ELECTROANALYTICAL CHEMISTRY 301 (1989).

[12] *See* U.S. DEP'T OF ENERGY, REPORT OF THE REVIEW OF LOW ENERGY NUCLEAR REACTIONS (2004), *available at* http://www.newenergytimes.com/DOE/DOE-CF-Final-120104.pdf.

[13] Woo Suk Hwang et al., *Evidence of a Pluripotent Human Embryonic Stem Cell Line Derived from a Cloned Blastocyst*, 303 SCIENCE 1669 (2004); Woo Suk Hwang et al., *Patient-Specific Embryonic Stem Cells Derived from Human SCNT Blastocysts*, 308 SCIENCE 1777 (2005).

[14] *See* Cho et al., *supra* note 10.

scientific field. Where experiments can be done quickly, using readily available equipment and techniques—for example, chemistry and molecular biology—repetition is common. In other fields, such as ecology and physics, where a single experiment may take years to complete or require exceptional funding or equipment, repetition of an experiment is rare. But even when the same exact experiment is not repeated, scientists are reluctant to accept the generality of a conclusion until it has been shown to apply repeatedly under different contexts. Thus, the capacity to share data from similar experiments, conducted by different individuals or lab groups, and to analyze it in different ways is also important to maintaining the integrity of science.

B. Open Communication and Data Sharing

Science progresses most rapidly when data are shared and made freely available. While there are few regulations that require scientists to share their data, social pressure and the expectation of reciprocity (those who share are shared with) promote the sharing of data.[15] The advent of the internet and the growing availability of electronic data resources and archives have provided more opportunities for scientists to access and to share data. This increasing availability of data (or the expectation that it should be) also has created new challenges, some of which involve legal issues, with regard to what types of data can (or should) be made available, if these data should be "free," how soon data should be made available or how long it can be withheld, and who has responsibility for archiving and maintaining these data so that they will continue to be available.

In the United States, researchers whose work is supported by federal grants or contracts are expected to make their data available to the public. Both the National Institutes of Health (NIH) and National Science Foundation (NSF) have data sharing policies recognizing that researchers should be accorded "exclusive access" to their data for a "reasonable period of time"—typically until the research has been published—with the expectation that after this period researchers will share their data.[16] Some NSF grant programs have

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[15] *See generally* COMM. ON RESPONSIBILITIES OF AUTHORSHIP IN THE BIOLOGICAL SCIENCES., NAT'L RESEARCH COUNCIL, SHARING PUBLICATION-RELATED DATA AND MATERIALS: RESPONSIBILITIES OF AUTHORSHIP IN THE LIFE SCIENCES (2003).

[16] The NIH's data policy is available at National Cancer Institute, U.S. NIH, Data Sharing Research Policy, http://dceg.cancer.gov/research/datapolicy (last visited Oct. 28, 2008); and the NSF's policy is available at NSF, General Grant Conditions (GC-1) (June 1, 2007), http://www.nsf.gov/pubs/policydocs/gc1_607.pdf.

specific criteria for proposal evaluation that require a plan for data sharing and management. Failure to comply with these instructions can result in the rejection of or refusal to review a proposal.

Even the most ardent proponents of data sharing agree that there are challenges to the open exchange of data.. While individual scientists may be willing to share their data, the costs and time to document, maintain, and store data often extend beyond the specific project. These issues have been the subject of a number of recent workshops sponsored by a Joint Working Group (JWG) on Data Sharing and Archiving funded by the NSF. The issue in these workshops has not been *if* a scientist should share data, but rather what can be done by professional societies, organizations, and institutes to promote data sharing. The value to society in advancing science—particularly in developing countries where the infrastructure to support science is limited—is seen as a compelling reason to develop universal opportunities to promote data sharing and access.

One critical issue in discussions of data sharing is the need to protect the ability of scientists to first publish their results and to allow them, their institutions, or funders—particularly private corporations or industry—to benefit from any financial gain that can be achieved from a scientific discovery. Patenting makes it possible for individual scientists to benefit from any commercial value that a scientific discovery will produce. Most scientific discoveries, however, even those that are patented, do not provide financial rewards to the individual—and so concerns about financial rewards are rarely an impediment to data sharing. There may be cultural incentives to encourage data sharing beyond tradition and the motivation to maintain the integrity of science. A recent review of citation rates of cancer clinical studies showed that those publications that made their data available were cited more frequently than those that did not.[17] The growing use of meta-analysis for evaluation of scientific hypotheses will increase the need for access to the original data[18] and perhaps provide further incentives for scientists to share their data. Conclusions from these meta-analyses are valuable for discussions of legal science as they provide a broader context for the results of individual studies and can reveal where the preponderance of evidence is in regard to a particular scientific hypothesis.

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[17] Heather A. Piwowar et al., *Sharing Detailed Research Data Is Associated with Increased Citation Rate*, PLoS ONE, Mar. 2007, at 1, *available at* http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0000308.

[18] *See infra* notes 24–25 and accompanying text (discussing meta-analysis).

C. Objective Interpretation of the Evidence and Statistical Inference

Scientists, above all, are supposed to be objective observers of nature. This sounds simple in the abstract, but is much more difficult in practice. Consider, for example, one of the most celebrated experiments in physics. In 1919, the British astronomer Arthur Eddington and his scientific colleague, Astronomer Royal Frank Dyson organized an expedition to test Einstein's newly formulated theory of general relatively, which predicts, among other things, that a massive object such as the sun should bend light that passes near it. A test of Einstein's light-bending prediction is possible during a solar eclipse, when the positions of stars located near the sun in the sky may be observed. The deflection in starlight caused by the sun's mass was measured at two different sites by two different teams during the 1919 eclipse. After analyzing the data, Eddington and his fellow scientists reported that the observations matched those predicted by Einstein's theory. Their result was heralded as an experimental confirmation of the new theory of general relatively, and it had a major impact on the theory's rapid acceptance. But a shadow of doubt was subsequently cast upon the impartiality of Eddington's conclusions.

Eddington was a supporter of Einstein's theory and, at the time, he was one of only a handful of scientists who understood its intricacies. Further, as a Quaker and a pacifist, Eddington was concerned about the bitter, nationalistic feelings that existed in England (and other parts of the world) against Germany following World War I. These factors may have influenced Eddington's objectivity in interpreting the data from his experiments. In addition, difficulties in transporting astronomical instruments to the remote observation sites, along with poor weather at one site, made the quality of the data obtained by Eddington and his fellow scientists less than ideal. In making his final calculations, Eddington was put into the position of having to choose between conflicting sets of observations and, in the end, he chose to ignore a data set that did not support Einstein's theory.

The challenges to impartiality faced by Eddington are similar to those faced by all scientists,[19] except in Eddington's case, his judgment was to play out on a grand stage. Two influential papers by John Earman and Clark Gylmour and Francis Everitt suggest that Eddington's decision to exclude the conflicting data was biased by his predisposition for Einstein's theory.[20] They also

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[19] *See* COMM. ON THE CONDUCT OF SCI., NAT'L ACAD. OF SCI., ON BEING A SCIENTIST (1989).

[20] *See* John Earman & Clark Glymour, *Relativity and Eclipses: The British Eclipse Expeditions of 1919 and Their Predecessors*, 11 HIST. STUD. PHYSICAL SCI. 49 (1980); C.W.F. Everitt, *Experimental Tests of*

questioned whether the measurement errors inherent in the calculations from the 1919 observations were so large as to make the test of Einstein's theory inconclusive. Stephen Hawking, in his popular book *A Brief History of Time*, states:

> This proof of a German theory by British scientists was hailed as a great act of reconciliation between the two countries after the war. It is ironic, therefore, that later examination of the photographs taken on that expedition showed the errors were as great as the effect they were trying to measure. Their measurement had been sheer luck, or a case of knowing the result they wanted to get, not an uncommon occurrence in science.[21]

These accounts have led to the "modern" view that the 1919 test of Einstein's theory was a case of scientists seeing what they wanted to see. A recent and very thorough examination of the case, however, shows that Eddington's analysis of the data was based on sound scientific judgment that "the results were roughly consistent with the prediction of Einstein's theory of General Relatively and firmly ruled out the only other theoretically predicted values."[22]

Eddington's test of Einstein's theory is a fascinating story, and it encapsulates many of the issues that face scientists with regard to being objective observers of nature. In Eddington's case, as in many others, open communication, unrestricted access to data, a detailed description of the analysis, and the repetition of experiments by other scientists combined to ensure the integrity of the experimental result. Since Eddington's initial test, the degree of light deflection predicted by Einstein's theory has been accurately confirmed many times. Scientists, however, must rely on more than their sound judgment to test a hypothesis. For example, how do we decide whether an observation or experimental result conforms to a predicted value? In most cases, scientists employ statistics to ensure the objective interpretation of data.

General Relativity: Past, Present and Future, *in* 4 PHYSICS AND CONTEMPORARY NEEDS 529 (Riazuddin ed., 1980). Two popular books echo this theme. *See* HARRY COLLINS & TREVOR PINCH, THE GOLEM: WHAT EVERYONE SHOULD KNOW ABOUT SCIENCE (1993); JOHN WALLER, EINSTEIN'S LUCK: THE TRUTH BEHIND SOME OF THE GREATEST SCIENTIFIC DISCOVERIES (2002).

[21] STEPHEN W. HAWKING, A BRIEF HISTORY OF TIME: FROM THE BIG BANG TO BLACK HOLES 32 (1988).

[22] Daniel Kennefick, Not Only Because of Theory: Dyson, Eddington and the Competing Myths of the 1919 Eclipse Expedition 1 (Sept. 5, 2007) (unpublished Ph.D. dissertation, California Institute of Technology), *available at* http://arxiv.org/ftp/arxiv/papers/0709/0709.0685.pdf.

A statistical test is used to determine whether a particular observation—or a set of observations—is consistent with a specific hypothesis or is due to chance.[23] Probability is an important part of statistical tests. Typically, a result is deemed statistically significant if there is less than a 5% probability that the observation occurred simply as the result of chance. There are two types of errors in statistics: A Type 1 error is concluding that a hypothesis is false when it is actually true. A Type 2 error is the reverse—failing to reject a hypothesis when it is false. The power to test a hypothesis and detect a difference is a function of (1) how variable the results are, (2) the magnitude of the effect, and (3) the number of observations, or size of the sample. The underlying heterogeneity that is typical of natural systems can make it challenging to detect effects that are small or there may be variable results depending on the size of the study or how it was conducted.

Meta-analysis is a statistical tool that combines the results from many different studies, thereby providing a powerful tool for assessing the repeatability of a result or the strength and generality of an effect.[24] Meta-analysis is commonly used in medical sciences and is useful in testing hypotheses in studies where sample sizes in individual studies are necessarily low. Concerns about the use of meta-analysis include the following: how the effect size is measured, any bias in what studies are included, the criteria used to make these decisions, and the reliance on published studies, which may reduce the number of studies of "no effect" (as these are typically more difficult to publish). Meta-analysis, however, remains an important tool for evaluating the effects of particular treatments on human and environmental health.[25]

D. Peer Review

Peer review is critical to the integrity of science—although it is not without its critics. Peer review is important in determining the caliber and quality of science that is published in journals and made available to the public. Articles published in journals that have peer review and that impose rigorous standards

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[23] *See generally* DESIGN AND ANALYSIS OF ECOLOGICAL EXPERIMENTS (Samuel M. Scheiner & Jessica Gurevitch eds., 1993).

[24] *See* Jessica Gurevitch et al., *Meta-Analysis in Ecology*, 32 ADVANCES ECOLOGICAL RES. 199 (2001); Larry V. Hedges & Ingram Olkin, *Nonparametric Estimators of Effect Size in Meta-Analysis*, 96 PSYCHOL. BULL. 573 (1984) (discussing non-parametric estimators for cases where observations are far from normally distributed).

[25] *See* Dan Jones, *Of Medicine and Meta-Analysis*, 7 NATURE REVS. DRUG DISCOVERY 376 (2008).

are viewed as higher quality and generally have greater impact than journals that do not. Evaluation of the paper by a peer group, typically two to three peers, is intended to assure that the science and ideas reported meet a set of standards for quality, innovation, and rigor that are the accepted norm for the discipline. Publication in a highly regarded peer-reviewed journal is equivalent to an intellectual "seal of approval" of the science that is reported.

Scientific peers are equals in the discipline and their review is expected to reflect their knowledge of and expertise in a particular field.[26] Peer review is typically anonymous and, perhaps most surprising to those outside of science, is generally done without compensation—it is viewed as a professional obligation and opportunity. The process relies on the contributions of thousands of scientists who volunteer their time to review manuscripts and provide their candid opinion of the quality and importance of the work reported. Most journals do not identify who has reviewed a particular paper, though some reviewers choose to identify themselves. Journals may publish the names of individuals who have provided reviews for them over some period of time. This serves as an acknowledgement of the service provided by these individuals and also demonstrates the caliber and quality of the reviewers used.

In some journals, authors can recommend preferred—and not preferred—individuals to review their paper. It is the responsibility and discretion of the editor handling the paper to consider these suggestions. Rarely do authors sue to obtain the names of reviewers when a paper is rejected. Instead, if they believe the work is valid and good they persist and submit it to another journal. Every scientific discipline can point to an idea or innovation in their discipline that was rejected by the established journals but became an important, revolutionary idea after being published elsewhere.[27]

Critics of peer review argue that it can impede the progress of science because it makes it more difficult for a new idea or innovation to be published if the results are "outside the norm" of the discipline.[28] Though initial publication of a new or revolutionary idea may be difficult, if a study is valid, and the authors persist, it can and will be published somewhere and the ideas

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[26] *See* Thomas H. Jukes, *Peer Review*, 265 NATURE 203, 203 (1977) (discussing importance of peer review and stating that "without peer review, scientific literature would become a Tower of Babel").

[27] *See, e.g.*, *id.* (describing Bohr's paper); Robert Edward Cook, *Raymond Lindeman and the Trophic-Dynamic Concept in Ecology*, 198 SCIENCE 22 (1977) (describing the rejection of Lindeman's work).

[28] *See, e.g.*, THOMAS S. KUHN, THE STRUCTURE OF SCIENTIFIC REVOLUTIONS (3d ed. 1996) (discussing various scientific paradigms).

and data will be made available for the broader scientific community to evaluate. Critics of peer review also question whether there are biases in the review process that may limit particular groups (e.g., women or individuals from less-established labs) from publishing their work in prestigious journals.[29]

Another challenge to the peer-review process involves a recent court case brought by a drug company challenging the confidentiality of peer review.[30] Lawyers for the drug company argued that the public has a right to know who reviewed papers that are being used in court cases regarding product liability. One of the issues in this case was whether confidentiality is a necessary part of the peer-review process and if it violates the public's right to know. Opponents of the request successfully argued that what the public wants is credible science and that confidential peer review is an important component of maintaining that credibility.[31]

Confidentiality contributes two important things to peer review that help to maintain scientific integrity. It allows for honest evaluation without fear of retribution—a colleague can provide a fair and critical review of a submitted paper without being concerned that the authors might retaliate by rejecting a paper or ranking them low on a future grant proposal. It also levels the playing field so that the advice of a young scientist is considered equal to that of a senior scientist. Peer review for grants (both panels and ad hoc) is structured to include a diversity of opinions, not only to promote the funding of new and exciting ideas, but also to assure that there is rigorous evaluation of proposals.[32]

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[29] Amber E. Budden et al., *Double-Blind Review Favours Increased Representation of Female Authors*, 23 TRENDS ECOLOGY & EVOLUTION 4 (2008).

[30] *See In re* Bextra & Celebrex Mktg. Sales Practices & Prod. Liab. Litig., 249 F.R.D. 8 (D. Mass. 2008) [hereinafter *Confidentiality Case*] (denying drug manufacturer's motion to compel disclosure of confidential peer-review information by the *New England Journal of Medicine*); Donald Kennedy, *Confidential Review—or Not?*, 319 SCIENCE 1009 (2008) [hereinafter Kennedy, *Confidential Review*] (discussing case and lamenting the implications if courts took away the confidentiality of the peer-review process); *see also* Donald Kennedy, *On the Way Out*, 319 SCIENCE 1161 (2008) [hereinafter Kennedy, *Way Out*] (acknowledging the flaws of the peer-review process but arguing it is the best process available).

[31] *See Confidentiality Case*, *supra note* 30, at 13–15; Kennedy, *Confidential Review*, *supra* note 30; Kennedy, *Way Out*, *supra* note 30.

[32] *See* NAT'L INST. OF HEALTH, 2007–2008 PEER REVIEW SELF-STUDY (2008), *available at* http://enhancing-peer-review.nih.gov/meetings/NIHPeerReviewReportFINALDRAFT.pdf.

II. THREATS TO SCIENTIFIC INTEGRITY

One of the hallmarks of the scientific method is open communication and the sharing of methods, data, and results. However, there are many real-world impediments to this ideal. We discuss some of these impediments below under the topics of politicizing science and freedom to publish. Neither threat is new—governments have and will continue to withhold or to control scientific information out of concerns for national security or the public good (e.g., the Manhattan Project). Private industry also clearly has the right to control the release of science that it has supported in order to protect its ability to capitalize financially on the research. The issue is not *if* there are circumstances where access to, and the free exchange of, scientific data can be limited; it is under what conditions this is appropriate.

A. Politicizing Science

Scientists working for a governmental agency or for industry may confront interference in their work that limits or controls what they do, how their research is reported, and who has access to the data. The most notorious example of this is *Lysenkoism*—the repressive and maniacal control of Soviet science that was promulgated by Trofim Lysenko and his followers in the Soviet Union.[33] Lysenko was a plant breeder who rejected the work of Gregor Mendel and the growing research on genetics. He was also a master of self-promotion and, with the support of the Soviet government under Joseph Stalin, maintained control and kept the study of genetics out of Soviet biology and agricultural research for over thirty years—from the mid-1930s to the 1960s. His ideas had little scientific support—in fact he rejected the scientific process as too slow and cumbersome to address the serious challenges in Soviet agriculture. He was quick to present his ideas to the Soviet press, *Pravda*, and relied on questionnaires given to peasants to support his ideas, rather than rigorous scientific tests. Undoubtedly, many factors contributed to the widespread support of Lysenko's ideas, but the result was the hijacking of science to support an ideology that limited the biological sciences in the Soviet Union for decades and contributed to widespread famine and crop failures.

While issues of national security can impose (and have imposed) reasonable limits on the public's access to research data or findings of a governmental agency, the Union for Concerned Scientists (UCS), a science-

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[33] *See* DAVID JORAVSKY, THE LYSENKO AFFAIR 187–227 (1970).

based nonprofit organization, has been particularly critical of the actions taken by the George W. Bush Administration to limit scientific exchange.[34] The UCS surveyed over 3,400 federal scientists working in fifteen governmental agencies during the Bush Administration, including the Environmental Protection Agency (EPA), the Fish and Wildlife Service (FWS), the National Ocean and Atmospheric Administration (NOAA), the Food and Drug Administration (FDA), and climate scientists working in multiple federal agencies. Based on these surveys, the UCS concluded that there was consistent and overt interference by the Bush Administration in the work done by federal scientists, limiting the integrity of science espoused by these agencies.[35] Their findings included documentation that scientists working in federal agencies feared retaliation for expressing their views about how their work was presented and had some publications blocked by the administration. The interference was widespread and involved scientists in nine of the fifteen surveyed federal agencies, including the EPA. These actions—omitting data, blocking testimony, and preventing the publication of results that were inconsistent with the administration's environmental policies—represent a serious threat to the integrity of science and should be of concern to all citizens.

B. Freedom to Publish

The ability of scientists to publish their research openly and freely is an important safeguard to scientific integrity. Again, scientists working for federal agencies under the Bush Administration report that efforts to publish their research have been suppressed through a variety of tactics.[36] These include directly removing materials from reports and limiting the ability of scientists to publish research in peer-reviewed journals. Industry can and does limit publication of research that it sponsors or conducts, and there have been notorious legal battles regarding the failure of industry to reveal the results of studies that have shown that their products or production practices are harmful. Industries can have legitimate concerns that justify delaying the publication of

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[34] Additional information can be found at the Union of Concerned Scientists' website at http://www.ucsusa.org/scientific_integrity (last visited Oct. 28, 2008).

[35] *Oversight Hearing on Science and Environmental Regulatory Decisions*: *Before the S. Subcomm. on Public Sector Solutions to Global Warming, Oversight, and Children's Health Protection of the S. Comm. on Environment and Public Works*, 110th Cong. (2008) (written testimony of Dr. Francesca Grifo, Director of the Scientific Integrity Program, UCS), *available at* http://epw.senate.gov/public/index.cfm?FuseAction=Files.View&FileStore_id=0872dd5f-e729-4d05-bc0c-470deaeef117.

[36] *Id.*

data from research that they have supported, such as the need to ascertain the impact on their products. But concerns over litigation may also limit a company's interest in releasing or even collecting data. For example, concerns over the impact of gene flow from genetically modified (GM) crop plants to wild relatives or non-GM varieties of crops raises a number of issues related to risk that could be addressed if research on the pollen (or seed) flow were collected or made available. Researchers working for industry may be reluctant to collect or release these data (or even prevented from doing so) out of concern that public reaction to this information may be harmful to the development and marketing of new crops. There is a considerable ongoing debate in the scientific literature regarding the potential of gene flow from GM crops to affect other species—not having the data available to consider these potentials impedes our understanding of complex evolutionary processes that could have important consequences for food production (and perhaps human health).

CONCLUSION

Science is a way of understanding the natural world. It relies on a process that can be slow, methodical, and cumbersome.[37] This can and does limit how quickly new ideas or solutions to important problems are made available. But to ignore or subvert this process for political expediency can result in the acceptance of false or pseudoscience.

Everyone has a responsibility to know how the scientific process works and to be able to differentiate between good science and pseudoscience. Science is not "just for geeks and smart kids" anymore. We live in a world where science is increasingly reported through venues that make it accessible to the general public (e.g., television, books, the internet). The reporting of science in these venues is typically *not* done by scientists—the majority of whom do not write well enough to communicate with an audience outside of their peers.[38] As a consequence, what is written about science may be incomplete, overstated, or worse, wrong. The vast majority of scientists *do not* support alternatives to Darwin's theory of evolution and most *do accept* that our planet is warming at an unprecedented rate.

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[37] *See* ROBERT M. HAZEN & JAMES TREFIL, SCIENCE MATTERS: ACHIEVING SCIENTIFIC LITERACY (1991).

[38] Some notable exceptions include Brian Greene's *The Elegant Universe*, David Sloan Wilson's *Evolution Is for Everyone*, and Michael Shermer's *Skeptic* magazine. *See* BRIAN GREENE, THE ELEGANT UNIVERSE (2008); WILSON, *supra* note 1; SKEPTIC, http://www.skeptic.com/.

Having the ability to differentiate between good, bad, and pseudoscience is increasingly important as we live in a world where technological advances and scientific information are increasingly part of our lives.[39] Many of the issues raised in this Symposium relate to this—judges, lawyers, and jurors are being presented with information described as "scientific fact" by experts who may differ in their training and reputability. It is not that scientists always agree—it is that we have an agreed-upon scientific method for challenging ideas with which we do not agree. Good science is not necessarily what is most popular, or what supports a particular political, social, or religious agenda. Good science is that set of ideas, hypotheses, and laws that can be tested and is repeatedly challenged by creative men and women who enjoy the challenge and the hard work that makes science (and being a scientist) a lively, stimulating, and delightful endeavor.

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[39] Brian Greene, Op-Ed., *Put a Little Science in Your Life*, N.Y. TIMES, June 1, 2008, at 14.