INTRODUCTION TO THE RESPONSIBLE CONDUCT OF RESEARCH

Climatologist Inez Fung's appreciation for the beauty of science brought her to the Massachusetts Institute of Technology where she received her doctoral degree in meteorology. "I used to think that clouds were just clouds," she says. "I never dreamed you could write equations to explain them—and I loved it."[1]

The rich satisfaction of understanding nature is one of the forces that keeps researchers rooted to their laboratory benches, climbing through the undergrowth of a sweltering jungle, or following the threads of a difficult theoretical problem. Observing or explaining something that no one has ever observed or explained before is a personal triumph that earns and deserves individual recognition. It also is a collective achievement, for in learning something new the discoverer both draws on and contributes to the body of knowledge held in common by all researchers.

Scientific research offers many satisfactions besides the exhilaration of discovery. Researchers seek to answer some of the most fundamental questions that humans can ask about nature. Their work can have a direct and immediate impact on the lives of people throughout the world. They are members of a community characterized by curiosity, cooperation, and intellectual rigor.

However, the rewards of science are not easily achieved. At the frontiers of research, new knowledge is elusive and hard won. Researchers often are subject to great personal and professional pressures. They must make difficult decisions about how to design investigations, how to present their results, and how to interact with colleagues. Failure to make the right decisions can waste time and resources, slow the advancement of knowledge, and even undermine professional and personal trust.

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[1]Skelton, R. *Forecast Earth: The Story of Climate Scientist Inez Fung*. Washington, DC: Joseph Henry Press, 2005.

THE TREATMENT OF DATA

In order to conduct research responsibly, graduate students need to understand how to treat data correctly. In 2002, the editors of the *Journal of Cell Biology* began to test the images in all accepted manuscripts to see if they had been altered in ways that violated the journal's guidelines. About a quarter of the papers had images that showed evidence of inappropriate manipulation. The editors requested the original data for these papers, compared the original data with the submitted images, and required that figures be remade to accord with the guidelines. In about 1 percent of the papers, the editors found evidence for what they termed "fraudulent manipulation" that affected conclusions drawn in the paper, resulting in the papers' rejection.

Researchers who manipulate their data in ways that deceive others, even if the manipulation seems insignificant at the time, are violating both the basic values and widely accepted professional standards of science. Researchers draw conclusions based on their observations of nature. If data are altered to present a case that is stronger than the data warrant, researchers fail to fulfill all three of the obligations described at the beginning of this guide. They mislead their colleagues and potentially impede progress in their field or research. They undermine their own authority and trustworthiness as researchers. And they introduce information into the scientific record that could cause harm to the broader society, as when the dangers of a medical treatment are understated.

This is particularly important in an age in which the Internet allows for an almost uncontrollably fast and extensive spread of information to an increasingly broad audience. Misleading or inaccurate data can thus have far-reaching and unpredictable consequences of a magnitude not known before the Internet and other modern communication technologies.

Misleading data can arise from poor experimental design or careless measurements as well as from improper manipulation. Over time, researchers have developed and have continually improved methods and tools designed to maintain the integrity of research. Some of these methods and tools are used within specific fields of research, such as statistical tests of significance, double-blind trials, and proper phrasing of questions on surveys. Others apply across all research fields, such as describing to others what one has done so that research data and results can be verified and extended.

Because of the critical importance of methods, scientific papers must include a description of the procedures used to produce the data, sufficient to permit reviewers and readers of a scientific paper to evaluate not only the validity of the data but also the reliability of the methods used to derive those data. If this information is not available, other researchers may be less likely to accept the data and the conclusions drawn from them. They also may be unable to reproduce accurately the conditions under which the data were derived.

The best methods will count for little if data are recorded incorrectly or haphazardly. The requirements for data collection differ among disciplines and research groups, but researchers have a fundamental obligation to create and maintain an accurate, accessible, and permanent record of what they have done in sufficient detail for others to check and replicate their work. Depending on the field, this obligation may require entering data into bound notebooks with sequentially numbered pages using permanent ink, using a computer application with secure data entry fields, identifying when and where work was done, and retaining data for specified lengths of time. In much industrial research and in some academic research, data notebooks need to be signed and dated by a witness on a daily basis.

Unfortunately, beginning researchers often receive little or no formal training in recording, analyzing, storing, or sharing data. Regularly scheduled meetings to discuss data issues and policies maintained by research groups and institutions can establish clear expectations and responsibilities.

The Selection of Data

Deborah, a third-year graduate student, and Kamala, a postdoctoral fellow, have made a series of measurements on a new experimental semiconductor material using an expensive neutron test at a national laboratory. When they return to their own laboratory and examine the data, a newly proposed mathematical explanation of the semiconductor's behavior predicts results indicated by a curve.

During the measurements at the national laboratory, Deborah and Kamala observed electrical power fluctuations that they could not control or predict were affecting their detector. They suspect the fluctuations affected some of their measurements, but they don't know which ones.

When Deborah and Kamala begin to write up their results to present at a lab meeting, which they know will be the first step in preparing a publication, Kamala suggests dropping two anomalous data points near the horizontal axis from the graph they are preparing. She says that due to their deviation from the theoretical curve, the low data points were obviously caused by the power fluctuations. Furthermore, the deviations were outside the expected error bars calculated for the remaining data points.

Deborah is concerned that dropping the two points could be seen as manipulating the data. She and Kamala could not be sure that any of their data points, if any, were affected by the power fluctuations. They also did not know if the theoretical prediction was valid. She wants to do a separate analysis that includes the points and discuss the issue in the lab meeting. But Kamala says that if they include the data points in their talk, others will think the issue important enough to discuss in a draft paper, which will make it harder to get the paper published. Instead, she and Deborah should use their professional judgment to drop the points now.

1. What factors should Kamala and Deborah take into account in deciding how to present the data from their experiment?
2. Should the new explanation predicting the results affect their deliberations?
3. Should a draft paper be prepared at this point?
4. If Deborah and Kamala can't agree on how the data should be presented, should one of them consider not being an author of the paper?

Most researchers are not required to share data with others as soon as the data are generated, although a few disciplines have adopted this standard to speed the pace of research. A period of confidentiality allows researchers to check the accuracy of their data and draw conclusions.

However, when a scientific paper or book is published, other researchers must have access to the data and research materials needed to support the conclusions stated in the publication if they are to verify and build on that research. Many research institutions, funding agencies, and scientific journals have policies that require the sharing of data and unique research materials. Given the expectation that data will be accessible, researchers who refuse to share the evidentiary basis behind their conclusions, or the materials needed to replicate published experiments, fail to maintain the standards of science.

In some cases, research data or materials may be too voluminous, unwieldy, or costly to share quickly and without expense. Nevertheless, researchers have a responsibility to devise ways to share their data and materials in the best ways possible. For example, centralized facilities or collaborative efforts can provide a cost-effective way of providing research materials or information from large databases. Examples include repositories established to maintain and distribute astronomical images, protein sequences, archaeological data, cell lines, reagents, and transgenic animals.

New issues in the treatment and sharing of data continue to arise as scientific disciplines evolve and new technologies appear. Some forms of data undergo extensive analysis before being recorded; consequently, sharing those data can require sharing the software and sometimes the hardware used to analyze them. Because digital technologies are rapidly changing, some data stored electronically may be inaccessible in a few years unless provisions are made to transport the data from one platform to another. New forms of publication are challenging traditional practices associated with publication and the evaluation of scholarly work.

MISTAKES AND NEGLIGENCE

All scientific research is susceptible to error. At the frontiers of knowledge, experimental techniques often are pushed to the limit, the signal can be difficult to separate from the noise, and even the question to be answered may not be well defined. In such an uncertain and fluid situation, identifying reliable data in a mass of confusing and sometimes contradictory observations can be extremely difficult.

Furthermore, researchers sometimes have to take risks to explore an innovative idea or observation. They may have to rely on a theoretical or experimental technique that is not fully developed, or they may have to extend a conjecture into new realms. Such risk taking does not excuse sloppy research, but it should not be condemned as misguided.

Finally, all researchers are human. They do not have limitless working time or access to unlimited resources. Even the most responsible researcher can make an honest mistake in the design of an experiment, the calibration of instruments, the recording of data, the interpretation of results, or other aspects of research.

Despite these difficulties, researchers have an obligation to the public, to their profession, and to themselves to be as accurate and as careful as possible. Scientific disciplines have developed methods and practices designed to minimize the possibility of mistakes, and failing to observe these methods violates the standards of science. Every scientific result must be carefully prepared, submitted to the peer review process, and scrutinized even after publication.

Beyond honest errors are mistakes caused by negligence. Haste, carelessness, inattention—any of a number of faults can lead to work that does not meet scientific standards or the practices of a discipline. Researchers who are negligent are placing their reputation, the work of their colleagues, and the public's confidence in science at risk. Errors can do serious damage both within science and in the broader society that relies on scientific results. Though science is built on the

Changing Knowledge

In the early part of the 20th century, astronomers engaged in a prolonged debate over what were then known as spiral nebulae—diffuse pinwheels of light that powerful telescopes revealed to be common in the night sky. Some astronomers thought that these nebulae were spiral galaxies like the Milky Way at such great distances from the Earth that individual stars could not be distinguished. Others believed that they were clouds of gas within our own galaxy.

One astronomer who thought that spiral nebulae were within the Milky Way, Adriaan van Maanen of the Mount Wilson Observatory, sought to resolve the issue by comparing photographs of the nebulae taken several years apart. After making a series of painstaking measurements, van Maanen announced that he had found roughly consistent unwinding motions in the nebulae. The detection of such motions indicated that the spirals had to be within the Milky Way, since motions would be impossible to detect in distant objects.

Van Maanen's reputation caused many astronomers to accept a galactic location for the nebulae. A few years later, however, van Maanen's colleague Edwin Hubble, using a new 100-inch telescope at Mount Wilson, conclusively demonstrated that the nebulae were in fact distant galaxies; van Maanen's observations had to be wrong.

Studies of van Maanen's procedures have not revealed any intentional misrepresentation or sources of systematic error. Rather, he was working at the limits of observational accuracy, and his expectations influenced his measurements. Even cautious researchers sometimes admit, "If I hadn't believed it, I never would have seen it."

idea that peers will validate results, actual replication is selective. It is not practical (or necessary) to reconstruct all the observations and theoretical constructs made by others. To make progress, researchers must trust that previous investigators performed the work in accordance with accepted standards.

Some mistakes in the scientific record are quickly corrected by subsequent work. But mistakes that mislead subsequent researchers can waste large amounts of time and resources. When such a mistake appears in a journal article or book, it should be corrected in a note, erratum (for a production error), or corrigendum (for an author's error). Mistakes in other documents that are part of the scientific record—including research proposals, laboratory records, progress reports, abstracts, theses, and internal reports—should be corrected in a way that maintains the integrity of the original record and at the same time keeps other researchers from building on the erroneous results reported in the original.

Discovering an Error

Two young faculty members—Marie, an epidemiologist in the medical school, and Yuan, a statistician in the mathematics department—have published two well-received papers about the spread of infections in populations. As Yuan is working on the simulation he has created to model infections, he realizes that a coding error has led to incorrect results that were published in the two papers. He sees, with great relief, that correcting the error does not change the average time it takes for an infection to spread. But the correct model exhibits greater uncertainty in its results, making predictions about the spread of an infection less definite.

When he discusses the problem with Marie, she argues against sending corrections to the journals where the two earlier articles were published. "Both papers will be seen as suspect if we do that, and the changes don't affect the main conclusions in the papers anyway," she says. Their next paper will contain results based on the corrected model, and Yuan can post the corrected model on his Web page.

1. What obligations do the authors owe their professional colleagues to correct the published record?
2. How should their decisions be affected by how the model is being used by others?
3. What other options exist beyond publishing a formal correction?

RESEARCH MISCONDUCT

Some research behaviors are so at odds with the core principles of science that they are treated very harshly by the scientific community and by institutions that oversee research. Anyone who engages in these behaviors is putting his or her scientific career at risk and is threatening the overall reputation of science and the health and welfare of the intended beneficiaries of research.

Collectively these actions have come to be known as scientific misconduct. A statement developed by the U.S. Office of Science and Technology Policy, which has been adopted by most research-funding agencies, defines misconduct as "fabrication, falsification, or plagiarism in proposing, performing, or reviewing research, or in reporting research results." According to the statement, the three elements of misconduct are defined as follows:

- Fabrication is "making up data or results."
- Falsification is "manipulating research materials, equipment, or processes, or changing or omitting data or results such that the research is not accurately represented in the research record."
- Plagiarism is "the appropriation of another person's ideas, processes, results, or words without giving appropriate credit."

In addition, the federal statement says that to be considered research misconduct, actions must represent a "significant departure from accepted practices," must have been "committed intentionally, or knowingly, or recklessly," and must be "proven by a preponderance of evidence." According to the statement, "research misconduct does not include differences of opinion."

Some research institutions and research-funding agencies define scientific research misconduct more broadly. These institutional definitions may add, for example, abuse of confidentiality in peer review, failure to allocate credit appropriately in scientific publications, not

A Breach of Trust

Beginning in 1998, a series of remarkable papers attracted great attention within the condensed matter physics community. The papers, based largely on work done at Bell Laboratories, described methods that could create carbon-based materials with long-sought properties, including superconductivity and molecular-level switching. However, when other materials scientists sought to reproduce or extend the results, they were unsuccessful.

In 2001, several physicists inside and outside Bell Laboratories began to notice anomalies in some of the papers. Several contained figures that were very similar, even though they described different experimental systems. Some graphs seemed too smooth to describe real-life systems. Suspicion quickly fell on a young researcher named Jan Hendrik Schön, who had helped create the materials, had made the physical measurements on them, and was a coauthor on all the papers.

Bell Laboratories convened a committee of five outside researchers to examine the results published in 25 papers. Schön, who had conducted part of the work in the laboratory where he did his Ph.D. at the University of Konstanz in Germany, told the committee that the devices he had studied were no longer running or had been thrown away. He also said that he had deleted his primary electronic data files because he did not have room to store them on his old computer and that he kept no data notebooks while he was performing the work.

The committee did not accept Schön's explanations and eventually concluded that he had engaged in fabrication in at least 16 of the 25 papers. Schön was fired from Bell Laboratories and later left the United States. In a letter to the committee, he wrote that "I admit I made various mistakes in my scientific work, which I deeply regret." Yet he maintained that he "observed experimentally the various physical effects reported in these publications."

The committee concluded that Schön acted alone and that his 20 coauthors on the papers were not guilty of scientific misconduct. However, the committee also raised the issue of the responsibility coauthors have to oversee the work of their colleagues, while acknowledging that no consensus yet exists on the extent of this responsibility. The senior author on several of the papers, all of which were later retracted, wrote that he should have asked Schön for more detailed data and checked his work more carefully, but that he trusted Schön to do his work honestly. In response to the incident, Bell Laboratories instituted new policies for data retention and internal review of results before publication. It also developed a new research ethics statement for its employees.

observing regulations governing research, failure to report misconduct, or retaliation against individuals who report misconduct to the list of behaviors that are considered misconduct. In addition, the National Science Foundation has retained a clause in its misconduct policies that includes behaviors that seriously deviate from commonly accepted research practices as possible misconduct.

A crucial distinction between falsification, fabrication, and plagiarism (sometimes called FFP) and error or negligence is the intent to deceive. When researchers intentionally deceive their colleagues by falsifying information, fabricating research results, or using others' words and ideas without giving credit, they are violating fundamental research standards and basic societal values. These actions are seen as

Fabrication in a Grant Proposal

Vijay, who has just finished his first year of graduate school, is applying to the National Science Foundation for a predoctoral fellowship. His work in a lab where he did a rotation project was later carried on successfully by others, and it appears that a manuscript will be prepared for publication by the end of the summer. However, the fellowship application deadline is June 1, and Vijay decides it would be advantageous to list a publication as "submitted" rather than "in progress." Without consulting the faculty member or other colleagues involved, Vijay makes up a title and author list for a "submitted" paper and cites it in his application.

After the application has been mailed, a lab member sees it and goes to the faculty member to ask about the "submitted" manuscript. Vijay admits to fabricating the submission of the paper but explains his actions by saying that he thought the practice was not uncommon in science. The faculty members in Vijay's department demand that he withdraw his grant proposal and dismiss him from the graduate program.

1. Do you think that researchers often exaggerate the publication status of their work in written materials?
2. Do you think the department acted too harshly in dismissing Vijay from the graduate program?
3. If Vijay later applied to a graduate program at another institution, does that institution have the right to know what happened?
4. What were Vijay's adviser's responsibilities in reviewing the application before it was submitted?

Is It Plagiarism?

Professor Lee is writing a proposal for a research grant, and the deadline for the proposal submission is two days from now. To complete the background section of the proposal, Lee copies a few isolated sentences of a journal paper written by another author. The copied sentences consist of brief, factual, one-sentence summaries of earlier articles closely related to the proposal, descriptions of basic concepts from textbooks, and definitions of standard mathematical notations. None of these ideas is due to the other author. Lee adds a one-sentence summary of the journal paper and cites it.

1. Does the copying of a few isolated sentences in this case constitute plagiarism?
2. By citing the journal paper, has Lee given proper credit to the other author?

the worst violations of scientific standards because they undermine the trust on which science is based.

However, intent can be difficult to establish. For example, because trust in science depends so heavily on the assumption that the origin and content of scientific ideas will be treated with respect, plagiarism is taken very seriously in science, even though it does not introduce spurious results into research records in the same way that fabrication and falsification do. But someone who plagiarizes may insist it was a mistake, either in note taking or in writing, and that there was no intent to deceive. Similarly, someone accused of falsification may contend that errors resulted from honest mistakes or negligence.

Within the scientific community, the effects of misconduct—in terms of lost time, damaged reputations, and feelings of personal betrayal—can be devastating. Individuals, institutions, and even entire research fields can suffer grievous setbacks from instances of fabrication, falsification, and plagiarism. Acts of misconduct also can draw the attention of the media, policymakers, and the general public, with negative consequences for all of science and, ultimately, for the public at large.

AUTHORSHIP AND THE ALLOCATION OF CREDIT

When a paper is published, the list of authors indicates who has contributed to the work. Apportioning credit for work done as a team can be difficult, but the peer recognition generated by authorship is important in a scientific career and needs to be allocated appropriately.

Authorship conventions may differ greatly among disciplines and among research groups. In some disciplines the group leader's name is always last, while in others it is always first. In some scientific fields, research supervisors' names rarely appear on papers, while in others the head of a research group is an author on almost every paper associated with the group. Some research groups and journals simply list authors alphabetically.

Many journals and professional societies have published guidelines that lay out the conventions for authorship in particular disciplines. Frank and open discussion of how these guidelines apply within a particular research project—as early in the research process as possible—can reduce later difficulties. Sometimes decisions about authorship cannot be made at the beginning of a project. In such cases, continuing discussion of the allocation of credit generally is preferable to making such decisions at the end of a project.

Decisions about authorship can be especially difficult in interdisciplinary collaborations or multigroup projects. Collaborators from different groups or scientific disciplines should be familiar with the conventions in all the fields involved in the collaboration. The best practice is for authorship criteria to be written down and shared among all collaborators.

Several considerations must be weighed in determining the proper division of credit between investigators working on a project. If one researcher has defined and put a project into motion and a second researcher is invited to join in later, the first researcher may receive much of the credit for the project even if the second researcher makes major contributions. Similarly, when an established researcher initiates a project, that individual may receive more credit than a beginning researcher who spends much of his or her time working on the project. When a beginning researcher makes an intellectual contribution to a project, that contribution deserves to be recognized, including when the work is undertaken independently of the laboratory's principal investigator. Established researchers are well aware of the importance of credit in science where traditions expect them to be generous in their allocation of credit to beginning researchers.

Sometimes a name is included in a list of authors even though that person had little or nothing to do with the content of a paper. Including "honorary," "guest," or "gift" authors dilutes the credit due the people who actually did the work, inflates the credentials of the added authors, and makes the proper attribution of credit more difficult. Journals, the administrators of research institutions, and researchers should all work to avoid this practice. Similarly, ghost authorship,

Who Gets Credit?

Robert has been working in a large engineering company for three years following his postdoctoral fellowship. Using computer simulations, he has developed a method to constrain the turbulent mixing that occurs near the walls of a tokomak fusion reactor. He has written a paper for *Physical Review* and has submitted it to the head of his research group for review. The head of the group says that the paper is fine but that, as the supervisor of the research, he needs to be included as an author of the paper. Yet Robert knows that his supervisor did not make any direct intellectual contribution to the paper.

1. How should Robert respond to his supervisor's demand to be an honorary author?
2. What ways might be possible to appeal the decision within the company?
3. What other resources exist that Robert can use in dealing with this issue?

where a person who writes a paper is not listed among the authors, misleads readers and also should be condemned.

Policies at most scientific journals state that a person should be listed as the author of a paper only if that person made a direct and substantial intellectual contribution to the design of the research, the interpretation of the data, or the drafting of the paper, although students will find that scientific fields and specific journals vary in their policies. Just providing the laboratory space for a project or furnishing a sample used in the research is not sufficient to be included as an author, though such contributions may be recognized in a footnote or in a separate acknowledgments section. The acknowledgments sections also can be used to thank others who contributed to the work reported by the paper.

The list of authors establishes accountability as well as credit. When a paper is found to contain errors, whether caused by mistakes or deceit, authors might wish to disavow responsibility, saying that they were not involved in the part of the paper containing the errors or that they had very little to do with the paper in general. However, an author who is willing to take credit for a paper must also bear responsibility for its errors or explain why he or she had no professional responsibility for the material in question.

The distribution of accountability can be especially difficult in interdisciplinary research. Authors from one discipline may say that they are not responsible for the accuracy of material provided by authors from another discipline. A contrasting view is that each author needs to be confident of the accuracy of everything in the paper—perhaps by having a trusted colleague read the parts of the paper outside one's own discipline. One obvious but often overlooked solution to this problem is to add a footnote accompanying the list of authors that apportions responsibility for different parts of the paper.

Who Should Get Credit for the Discovery of Pulsars?

A much-discussed example of the difficulties associated with allocating credit between beginning and established researchers was the 1967 discovery of pulsars by Jocelyn Bell, then a 24-year-old graduate student. Over the previous two years, Bell and several other students, under the supervision of Bell's thesis adviser, Anthony Hewish, had built a 4.5-acre radio telescope to investigate scintillating radio sources in the sky. After the telescope began functioning, Bell was in charge of operating it and analyzing its data under Hewish's direction. One day Bell noticed "a bit of scruff" on the data chart. She remembered seeing the same signal earlier, and by measuring the period of its recurrence, she determined that it had to be coming from an extraterrestrial source. Together Bell and Hewish analyzed the signal and found several similar examples elsewhere in the sky. After discarding the idea that the signals were coming from an extraterrestrial intelligence, Hewish, Bell, and three other people involved in the project published a paper announcing the discovery, which was given the name "pulsar" by a British science reporter.

Many argued that Bell should have shared the Nobel Prize awarded to Hewish for the discovery, saying that her recognition of the signal was the crucial act of discovery. Others, including Bell herself, said that she received adequate recognition in other ways and should not have been so lavishly rewarded for doing what a graduate student is expected to do in a project conceived and set up by others.