CHAPTER 1

What Is Scientific Writing?

State your facts as simply as possible, even boldly. No one wants flowers of eloquence or literary ornaments in a research article.

—R. B. McKerrow

THE SCOPE OF SCIENTIFIC WRITING

The term *scientific writing* commonly denotes the reporting of original research in journals, through scientific papers in standard format. In its broader sense, scientific writing also includes communication about science through other types of journal articles, such as review papers summarizing and integrating previously published research. And in a still broader sense, it includes other types of professional communication by scientists—for example, grant proposals, oral presentations, and poster presentations. Related endeavors include writing about science for the public, sometimes called *science writing*.

THE NEED FOR CLARITY

The key characteristic of scientific writing is clarity. Successful scientific experimentation is the result of a clear mind attacking a clearly stated problem and producing clearly stated conclusions. Ideally, clarity should be a characteristic of any type of communication; however, when something is being said *for the first time*, clarity is essential. Most scientific papers, those published in our primary research journals, are accepted for publication precisely because they *do* contribute *new* knowledge. Hence, we should demand absolute clarity in scientific writing.

RECEIVING THE SIGNALS

Most people have no doubt heard this question: If a tree falls in the forest and there is no one there to hear it fall, does it make a sound? The correct answer is no. Sound is more than pressure waves, and indeed there can be no sound without a hearer.

And similarly, scientific communication is a two-way process. Just as a signal of any kind is useless unless it is perceived, a published scientific paper (signal) is useless unless it is both received *and* understood by its intended audience. Thus we can restate the axiom of science as follows: A scientific experiment is not complete until the results have been published *and understood.* Publication is no more than pressure waves unless the published paper is understood. Too many scientific papers fall silently in the woods.

UNDERSTANDING THE SIGNALS

Scientific writing is the transmission of a clear signal to a recipient. The words of the signal should be as clear, simple, and well ordered as possible. In scientific writing, there is little need for ornamentation. Flowery literary embellishments—metaphors, similes, idiomatic expressions—are very likely to cause confusion and should seldom be used in research papers.

Science is simply too important to be communicated in anything other than words of certain meaning. And the meaning should be clear and certain not just to peers of the author, but also to students just embarking on their careers, to scientists reading outside their own narrow disciplines, and *especially* to those readers (most readers today) whose native language is other than English.

Many kinds of writing are designed for entertainment. Scientific writing has a different purpose: to communicate new scientific findings. Scientific writing should be as clear and simple as possible.

ORGANIZATION AND LANGUAGE IN SCIENTIFIC WRITING

Effective organization is a key to communicating clearly and efficiently in science. Such organization includes following the standard format for a scientific paper. It also includes organizing ideas logically within that format.

In addition to organization, the second principal ingredient of a scientific paper should be appropriate language. This book keeps emphasizing proper use of English because many scientists have trouble in this area. All scientists must learn to use the English language with precision. A book (Day and Sakaduski 2011) wholly concerned with English for scientists is available.

If scientifically determined knowledge is at least as important as any other knowledge, it must be communicated effectively, clearly, in words of certain meaning. The scientist, to succeed in this endeavor, must therefore be literate. David B. Truman, when he was dean of Columbia University, said it well: "In the complexities of contemporary existence the specialist who is trained but uneducated, technically skilled but culturally incompetent, is a menace."

Given that the ultimate result of scientific research is publication, it is surprising that many scientists neglect the responsibilities involved. A scientist will spend months or years of hard work to secure data, and then unconcernedly let much of their value be lost because of a lack of interest in the communication process. The same scientist who will overcome tremendous obstacles to carry out a measurement to the fourth decimal place will be in deep slumber while a typographical error changes micrograms per milliliter to milligrams per milliliter.

English need not be difficult. In scientific writing, we say, "The best English is that which gives the sense in the fewest short words" (a dictum printed for some years in the *Journal of Bacteriology*'s instructions to authors). Literary devices, metaphors and the like, divert attention from substance to style. They should be used rarely in scientific writing.

letter to the scientist. If the paper was accepted, the scientist made the needed revisions and mailed back a final version of the manuscript. A copyeditor edited the paper by hand, and a compositor re-keyboarded the manuscript. Once the paper thus was typeset, a copy was mailed to the scientist, who checked for typographical errors and mailed back corrections. Before the paper was published, the scientist ordered reprints of the paper, largely for fellow scientists who lacked access to libraries containing the journal or lacked access to a photocopier.

Today the process has changed greatly. Word processors, graphics programs, digital photography, and the Internet have facilitated preparation and dissemination of scientific papers. Many journals throughout the world have online systems for manuscript submission and peer review. Editors and authors communicate electronically. Manuscript editors typically edit papers online, and authors electronically receive typeset proofs of their papers for inspection. Journals are available online as well as in print—and sometimes instead of in print. At some journals, electronic extras, such as appendixes and video clips, supplement online papers. Many journals are openly accessible online, either starting at the time of publication or after a lag period. In addition, readers often can access papers through the authors' websites or through resources at the authors' institutions or can request electronic reprints. Some of the changes have increased the technical demands on authors, but overall they have hastened and eased the publication process and improved service to readers.

Whereas much regarding the mechanics of publication has changed, much else has stayed the same. Items that persist include the basic structure of a scientific paper, the basic process by which scientific papers are accepted for publication, the basic ethical norms in scientific publication, and the basic features of good scientific prose. In particular, in many fields of science, the IMRAD structure for scientific papers remains dominant.

THE IMRAD STORY

The early journals published papers that we call descriptive. Typically, a scientist would report, "First, I saw this, and then I saw that," or "First, I did this, and then I did that." Often the observations were in simple chronological order.

This descriptive style was appropriate for the kind of science then being reported. In fact, this straightforward style of reporting still is sometimes used in "letters" journals, case reports in medicine, geological surveys, and so forth.

By the second half of the 19th century, science was beginning to move fast and in increasingly sophisticated ways. Microbiology serves as an example.

Especially through the work of Louis Pasteur, who confirmed the germ theory of disease and developed pure-culture methods of studying microorganisms, both science and the reporting of science made great advances.

At this time, methodology became all-important. To quiet his critics, many of whom were fanatic believers in the theory of spontaneous generation, Pasteur found it necessary to describe his experiments in exquisite detail. Because reasonably competent peers could reproduce Pasteur's experiments, the principle of *reproducibility of experiments* became a fundamental tenet of the philosophy of science, and a separate methods section led the way toward the highly structured IMRAD format.

The work of Pasteur was followed, in the early 1900s, by the work of Paul Ehrlich and, in the 1930s, by the work of Gerhard Domagk (sulfa drugs). World War II prompted the development of penicillin (first described by Alexander Fleming in 1929). Streptomycin was reported in 1944, and soon after World War II the mad but wonderful search for "miracle drugs" produced the tetracyclines and dozens of other effective antibiotics.

As these advances were pouring out of medical research laboratories after World War II, it was logical that investment in research would greatly increase. In the United States, this positive inducement to support science was soon (in 1957) joined by a negative factor when the Soviets flew *Sputnik* around our planet. In the following years, the U.S. government (and others) poured additional billions of dollars into scientific research.

Money produced science. And science produced papers. Mountains of them. The result was powerful pressure on the existing (and the many new) journals. Journal editors, in self-defense if for no other reason, began to demand that manuscripts be concisely written and well organized. Journal space became too precious to be wasted on verbosity or redundancy. The IMRAD format, which had been slowly progressing since the latter part of the 19th century, now came into almost universal use in research journals. Some editors espoused IMRAD because they became convinced that it was the simplest and most logical way to communicate research results. Other editors, perhaps not convinced by the simple logic of IMRAD, nonetheless hopped on the bandwagon because the rigidity of IMRAD did indeed save space (and expense) in the journals and because IMRAD made life easier for editors and referees by indexing the major parts of a manuscript.

The logic of IMRAD can be defined in question form: What question (problem) was studied? The answer is the introduction. How was the problem studied? The answer is the methods. What were the findings? The answer is the results. What do these findings mean? The answer is the discussion.

It now seems clear that the simple logic of IMRAD does help the author organize and write the manuscript, and IMRAD provides an easy road map for editors, referees, and ultimately readers to follow in reading the paper.

Although the IMRAD format is widely used, it is not the only format for scientific papers. For example, the methods section appears at the end of papers in some journals. In some journals, there is a combined results and discussion section. In some, a conclusions section appears at the end. In papers about research in which results of one experiment determine the approach taken in the next, methods sections and results sections can alternate. In some papers, especially in the social sciences, a long literature review section may appear near the beginning of the paper. Thus, although the IMRAD format is often the norm, other possibilities include IRDAM, IMRADC, IMRMRMRD, ILMRAD, and more.

Later in this book, we discuss components of a scientific paper in the order in which they appear in the IMRAD format. However, most of our advice on each component is relevant regardless of the structure used by the journal to which you will submit your paper. Before writing your paper, be sure, of course, to determine which structure is appropriate for the journal to which you will submit it. To do so, read the journal's instructions to authors and look at papers similar to yours that have appeared in the journal. These actions are parts of approaching a writing project—the subject of our next chapter.

CHAPTER 3

Approaching a Writing Project

Writing is easy. All you do is stare at a blank sheet of paper until drops of blood form on your forehead.

—Gene Fowler

ESTABLISHING THE MIND-SET

The thought of preparing a piece of scientific writing can intimidate even the best writers. However, establishing a suitable mind-set and taking a suitable approach can make the task manageable. Perhaps most basic, remember that you are writing to communicate, not to impress. Readers of scientific papers want to know what you did, what you found, and what it means; they are not seeking great literary merit. If you do good research and present it clearly, you will please and satisfy readers. Indeed, in scientific writing, readers should notice mainly the content, not the style.

Realize that those reading your work want you to do well. They are not out to thwart you. Journal editors are delighted to receive good papers; ditto for the scientists they enlist as referees (peer reviewers) to help evaluate your work. Likewise, if you are a student, professors want you to do well. Yes, these people often make constructive criticisms. But they are not doing so because they dislike you; rather, they do so because they want your work to succeed. Do not be paralyzed by the prospect of criticism. Rather, feel fortunate that you will receive feedback that can help your writing to be its best.

CHAPTER 4

What Is a Scientific Paper?

Without publication, science is dead.

—Gerard Piel

DEFINITION OF A SCIENTIFIC PAPER

A scientific paper is a written and published report describing original research results. That short definition must be qualified, however, by noting that a scientific paper must be written in a certain way, as defined by tradition, editorial practice, scientific ethics, and the interplay of printing and publishing procedures.

To properly define "scientific paper," we must define the mechanism that creates a scientific paper, namely, valid (that is, primary) publication. Abstracts, theses, conference reports, and many other types of literature are published, but such publications do not normally meet the test of valid publication. Further, even if a scientific paper meets all the other tests (discussed below), it is not validly published if it is published in the wrong place. That is, a relatively poor research report, but one that meets the tests, is validly published if accepted and published in the right place (a primary journal or other primary publication); a superbly prepared research report is not validly published if published in the wrong place. Most of the government literature and conference literature, as well as institutional bulletins and other ephemeral publications, do not qualify as primary literature.

Many people have struggled with the definition of primary publication (valid publication), from which is derived the definition of a scientific paper. The Council of Biology Editors (CBE), now the Council of Science Editors (CSE), arrived at the following definition (Council of Biology Editors 1968, p. 2):

> An acceptable primary scientific publication must be the first disclosure containing sufficient information to enable peers (1) to assess observations, (2) to repeat experiments, and (3) to evaluate intellectual processes; moreover, it must be susceptible to sensory perception, essentially permanent, available to the scientific community without restriction, and available for regular screening by one or more of the major recognized secondary services (e.g., currently, Biological Abstracts, Chemical Abstracts, Index Medicus, Excerpta Medica, Bibliography of Agriculture, etc., in the United States and similar services in other countries).

At first reading, this definition may seem excessively complex, or at least verbose. But those who had a hand in drafting it weighed each word carefully and doubted that an acceptable definition could be provided in appreciably fewer words. Because it is important that students, authors, editors, and all others concerned understand what a scientific paper is and what it is not, it may be helpful to work through this definition to see what it really means.

"An acceptable primary scientific publication" must be "the first disclosure." Certainly, first disclosure of new research data often takes place via oral presentation at a scientific meeting. But the thrust of the CBE statement is that disclosure is more than disgorgement by the author; effective first disclosure is accomplished *only* when the disclosure takes a form that allows the peers of the author (either now or in the future) to fully comprehend and use that which is disclosed.

Thus, sufficient information must be presented so that potential users of the data can (1) assess observations, (2) repeat experiments, and (3) evaluate intellectual processes. (Are the author's conclusions justified by the data?) Then, the disclosure must be "susceptible to sensory perception." This may seem an awkward phrase, because in normal practice it simply means published; however, this definition provides for disclosure not just in terms of printed visual materials (printed journals and the no longer widely used media called microfilm and microfiche) but also in nonprint, nonvisual forms. For example, "publication" in the form of audio recordings, if that publication met the other tests provided in the definition, would constitute effective publication. And, certainly, electronic journals meet the definition of valid publication. (Or, as one wag observed: "Electronic publishing has the capability to add a whole new dementia to the way people obtain and read literature.") What about material posted on a website? Views have varied and can depend on the nature of the material posted. For the most current information, consult materials from professional organizations and journals in your field.

Regardless of the form of publication, that form must be essentially permanent (often not the case for websites), must be made available to the scientific community without restriction (for example, in a journal that is openly accessible online or to which subscriptions are available), and must be made available to information-retrieval services (Biological Abstracts, Chemical Abstracts, MEDLINE, etc.). Thus, publications such as newsletters, corporate publications, and controlled-circulation journals, many of which are of value for their news or other features, generally cannot serve as repositories for scientific knowledge.

To restate the CBE definition in simpler but not more accurate terms, primary publication is (1) the first publication of original research results, (2) in a form whereby peers of the author can repeat the experiments and test the conclusions, and (3) in a journal or other source document readily available within the scientific community. To understand this definition, however, we must add an important caveat. The part of the definition that refers to "peers of the author" is accepted as meaning prepublication peer review. Thus, by definition, scientific papers are published in peer-reviewed publications.

This question of definition has been belabored above for two reasons. First, the entire community of science has long labored with an inefficient, costly system of scientific communication precisely because it (authors, editors, publishers) have been unable or unwilling to define primary publication. As a result, much of the literature has been buried in meeting abstracts, obscure conference reports, government documents, or books or journals of minuscule circulation. Other papers, in the same or slightly altered form, are published more than once; occasionally, this is due to the lack of definition as to which conference reports, books, and compilations are (or should be) primary publications and which are not. Redundancy and confusion result. Second, a scientific paper is, by definition, a particular kind of document containing certain specified kinds of information, typically in a prescribed (IMRAD) order. If the graduate student or the budding scientist (and even some of those scientists who have already published many papers) can fully grasp the significance of this definition, the writing task might be a great deal easier. Confusion results from an amorphous task. The easy task is the one in which you know exactly what must be done and in exactly what order it must be done.

ORGANIZATION OF A SCIENTIFIC PAPER

A scientific paper is organized to meet the needs of valid publication. It is, or should be, highly stylized, with distinctive and clearly evident component parts. The most common labeling of the component parts, in the basic sciences, is introduction, methods, results, and discussion (hence the acronym IMRAD). Actually, the heading "Materials and Methods" may be more common than the simpler "Methods," but the latter form was used in the acronym.

Some of us have taught and recommended the IMRAD approach for many years. Until relatively recently, however, several somewhat different systems of organization were preferred by some journals and some editors. The tendency toward uniformity has increased since the IMRAD system was prescribed as a standard by the American National Standards Institute, first in 1972 and again in 1979 (American National Standards Institute, 1979a). Some journals use a variation of IMRAD in which methods appear last rather than second. Perhaps we should call this IRDAM. In some journals, details regarding methods commonly appear in figure captions.

The basic IMRAD order is so eminently logical that, increasingly, it is used for many other types of expository writing. Whether one is writing an article about chemistry, archaeology, economics, or crime in the street, the IMRAD format is often the best choice.

This point is generally true for papers reporting laboratory studies. There are, of course, exceptions. As examples, reports of field studies in the earth sciences and many clinical case reports in the medical sciences do not readily lend themselves to this kind of organization. However, even in these descriptive papers, the same logical progression from problem to solution is often appropriate.

Occasionally, the organization of laboratory papers must be different. If a number of methods were used to achieve directly related results, it might be desirable to combine the materials and methods and the results into an integrated experimental section. In some fields and for some types of results, a combined results and discussion section is usual or desirable. In addition, many primary journals publish notes or short communications, in which the IMRAD organization is abridged.

Various types of organization are used in descriptive areas of science. To determine how to organize such papers and which general headings to use, refer to the instructions to authors of your target journal and look at analogous papers the journal has published. Also, you can obtain general information from appropriate source books. For example, types of medical papers are described by Huth (1999), Peat and others (2002), Taylor (2005), and contributors to a multiauthor guide (Hall 2008); types of engineering papers and reports are outlined by Michaelson (1990) and by Beer and McMurrey (2009). Indeed, even if a paper will appear in the IMRAD format, books on writing in one's own discipline can be worth consulting. Examples of such books include those in biomedical science by Zeiger (2000); the health sciences by Lang (2010); in chemistry by Ebel, Bliefert, and Russey (2004); and in psychology by Sternberg and Sternberg (2010).

In short, the preparation of a scientific paper has less to do with literary skill than with *organization*. A scientific paper is not literature. The preparer of a scientific paper is not an author in the literary sense.

Some old-fashioned colleagues think that scientific papers should be literature, that the style and flair of an author should be clearly evident, and that variations in style encourage the interest of the reader. Scientists should indeed be interested in reading literature, and perhaps even in writing literature, but the communication of research results is a more prosaic procedure. As Booth (1981) put it, "Grandiloquence has no place in scientific writing."

Today, the average scientist, to keep up with a field, must examine the data reported in a very large number of papers. Also, English, the international language of science, is a second language for many scientists. Therefore, scientists (and of course editors) must demand a system of reporting data that is uniform, concise, and readily understandable.

OTHER DEFINITIONS

If *scientific paper* is the term for an original research report, how should this be distinguished from research reports that are not original, are not scientific, or somehow fail to qualify as scientific papers? Some specific terms are commonly used: *review paper, conference report,* and *meeting abstract.*

A review paper may review almost anything, most typically the recent work in a defined subject area or the work of a particular individual or group. Thus, the review paper is designed to summarize, analyze, evaluate, or synthesize information that *has already been published* (research reports in primary journals). Although much or all of the material in a review paper has previously been published, the problem of dual publication (duplicate publication of original data) does not normally arise because the review nature of the work is usually obvious—often from the title of the periodical, such as *Microbiology and Molecular Biology Reviews* or *Annual Review of Astronomy and Astrophysics.* Do not assume, however, that reviews contain nothing new. From the best review papers come new syntheses, new ideas and theories, and even new paradigms.

A conference report is a paper published in a book or journal as part of the proceedings of a symposium, national or international congress, workshop, roundtable, or the like. Such conferences commonly are not designed for the presentation of original data, and the resultant proceedings (in a book or journal) do not qualify as primary publications. Conference presentations often are review papers, presenting reviews of the recent work of particular scientists or recent work in particular laboratories. Material at some conferences (especially the exciting ones) is in the form of preliminary reports, in which new, original data are presented, often accompanied by interesting speculation. But usually, these preliminary reports do not qualify, nor are they intended to qualify, as scientific papers. Later, often much later, such work may be validly published in a primary journal; by this time, the loose ends have been tied down, essential experimental details have been described (so that a competent worker could repeat the experiments), and previous speculation has matured into conclusions.

Therefore, the vast conference literature that appears normally is not *primary.* If original data are presented in such contributions, the data can and should be published (or republished) in an archival (primary) journal. Otherwise, the information may essentially be lost. If publication in a primary journal follows publication in a conference report, permission from the original publisher may be needed to reprint figures and other items (*see* Chapter 19, "Rights and Permissions"), but the more fundamental problem of dual publication normally does not and should not arise.

Meeting abstracts may be brief or relatively extensive. Although they can and generally do contain original information, they are not primary publications, and publication of an abstract should not preclude later publication of the full report.

Traditionally, there was little confusion regarding the typical one-paragraph abstracts published as part of the program or distributed along with the program at a national meeting or international congress. It was usually understood that many of the papers presented at these meetings would later be submitted for publication in primary journals. More recently, however, there has been a trend toward extended abstracts (or *synoptics*). The extended abstract can supply almost as much information as a full paper; mainly it lacks the experimental detail. However, precisely because it lacks experimental detail, it cannot qualify as a scientific paper.

Those involved with publishing these materials should see the importance of careful definition of the different types of papers. More and more publishers, conference organizers, and individual scientists are agreeing on these basic definitions, and their general acceptance will greatly clarify both primary and secondary communication of scientific information.

CHAPTER 7

How to Prepare the Title

First impressions are strong impressions; a title ought therefore to be well studied, and to give, so far as its limits permit, a definite and concise indication of what is to come.

—T. Clifford Allbutt

IMPORTANCE OF THE TITLE

In preparing a title for a paper, you would do well to remember one salient fact: That title will be read by thousands of people. Perhaps few people, if any, will read the entire paper, but many people will read the title, either in the original journal or in one of the secondary (abstracting and indexing) databases. Therefore, all words in the title should be chosen with great care, and their association with one another must be carefully managed. Perhaps the most common error in defective titles, and certainly the most damaging one in terms of comprehension, is faulty syntax (word order).

What is a good title? We define it as the fewest possible words that adequately describe the contents of the paper.

Remember that the indexing and abstracting services depend heavily on the accuracy of the title, as do individual computerized literature-retrieval systems. An improperly titled paper may be virtually lost and never reach its intended audience.

Some authors mistakenly sacrifice clarity in an attempt to be witty. The title of a paper need not, and generally should not, be clever. It must, however, be clear. An example (adapted from Halm and Landon 2007): "Association between Diuretic Use and Cardiovascular Mortality" could be an adequate title. The authors should resist the temptation to use instead "Dying to Pee."

LENGTH OF THE TITLE

Occasionally, titles are too short. A paper was submitted to the *Journal of Bacteriology* with the title "Studies on *Brucella*." Obviously, such a title was not very helpful to the potential reader. Was the study taxonomic, genetic, biochemical, or medical? We would certainly want to know at least that much.

Much more often, titles are too long. Ironically, long titles are often less meaningful than short ones. A century or so ago, when science was less specialized, titles tended to be long and nonspecific, such as "On the addition to the method of microscopic research by a new way of producing colour-contrast between an object and its background or between definite parts of the object itself" (Rheinberg J, *J. R. Microsc. Soc.* 1896: 373). That certainly sounds like a poor title; perhaps it would make a good abstract.

Not only scientists have written rambling titles. Consider this one from the year 1705: *A Wedding Ring Fit for the Finger, or the Salve of Divinity on the Sore of Humanity with directions to those men that want wives, how to choose them, and to those women that have husbands, how to use them.* Ironically, this title appeared on a miniature book (Bernard, A. Now all we need is a title: famous book titles and how they got that way. New York: Norton, 1995, p. 58).

Without question, most excessively long titles contain "waste" words. Often, these waste words appear right at the start of the title, words such as "Studies on," "Investigations on," and "Observations on." An opening *A, An,* or *The* is also a waste word. Certainly, such words are useless for indexing purposes.

NEED FOR SPECIFIC TITLES

Let us analyze a sample title: "Action of Antibiotics on Bacteria." Is it a good title? In *form* it is; it is short and carries no excess baggage (waste words). Certainly, it would not be improved by changing it to "Preliminary Observations on the Effect of Certain Antibiotics on Various Species of Bacteria." However (and this brings us to the next point), most titles that are too short are too short because they include general rather than specific terms.

We can safely assume that the study introduced by the above title did *not* test the effect of *all* antibiotics on *all* kinds of bacteria. Therefore, the title is essentially meaningless. If only one or a few antibiotics were studied, they should be individually listed in the title. If only one or a few organisms were tested, they should be individually listed in the title. If the number of antibiotics or organisms was awkwardly large for listing in the title, perhaps a group name could have been substituted. Examples of more acceptable titles are the following:

"Action of Streptomycin on *Mycobacterium tuberculosis*"
"Action of Streptomycin, Neomycin, and Tetracycline on Gram-Positive Bacteria"
"Action of Polyene Antibiotics on Plant-Pathogenic Bacteria"
"Action of Various Antifungal Antibiotics on *Candida albicans* and *Aspergillus fumigatus*"

Although these titles are more acceptable than the sample, they are not especially good because they are still too general. If the "Action of" can be defined easily, the meaning might be clearer. For example, the first title might have been phrased "Inhibition of Growth of *Mycobacterium tuberculosis* by Streptomycin."

Long ago, Leeuwenhoek used the word "animalcules," a descriptive but not very specific word. In the 1930s, Howard Raistrick published an important series of papers under the title "Studies on Bacteria." A similar paper today would have a much more specific title. If the study featured an organism, the title would give the genus and species and possibly even the strain number. If the study featured an enzyme in an organism, the title would not be anything like "Enzymes in Bacteria." It would be something like "Dihydrofolate Reductase Produced by *Bacillus subtilis*."

IMPORTANCE OF SYNTAX

In titles, be especially careful of syntax. Most of the grammatical errors in titles are due to faulty word order.

A paper was submitted to the *Journal of Bacteriology* with the title "Mechanism of Suppression of Nontransmissible Pneumonia in Mice Induced by Newcastle Disease Virus." Unless this author had somehow managed to demonstrate spontaneous generation, it must have been the pneumonia that was induced and not the mice. (The title should have read: "Mechanism of Suppression of Nontransmissible Pneumonia Induced in Mice by Newcastle Disease Virus.")

If you no longer believe that babies result from a visit by the stork, we offer this title (*Am. J. Clin. Pathol.* 52:42, 1969): "Multiple Infections among Newborns Resulting from Implantation with *Staphylococcus aureus* 502A." (Is this the "Staph of Life"?)

Another example (*Clin. Res.* 8:134, 1960): "Preliminary Canine and Clinical Evaluation of a New Antitumor Agent, Streptovitacin." When that dog gets through evaluating streptovitacin, we've got some work we'd like that dog to look over.

As a grammatical aside, please be careful when you use "using." The word "using" might well be the most common dangling participle in scientific writing. Either there are some more smart dogs, or "using" is misused in this sentence from a recent manuscript: "Using a fiberoptic bronchoscope, dogs were immunized with sheep red blood cells."

Dogs aren't the only smart animals. A manuscript was submitted to the *Journal of Bacteriology* under the title "Isolation of Antigens from Monkeys Using Complement-Fixation Techniques."

Even bacteria are smart. A manuscript was submitted to the *Journal of Clinical Microbiology* under the title "Characterization of Bacteria Causing Mastitis by Gas-Liquid Chromatography." Isn't it wonderful that bacteria can use GLC?

THE TITLE AS A LABEL

The title of a paper is a label. It normally is not a sentence. Because it is not a sentence, with the usual subject, verb, object arrangement, it is simpler than a sentence (or, at least, shorter), but the order of the words becomes even more important.

Actually, a few journals do permit a title to be a sentence. An example of such a title: "Phosphatidic Acid Is a pH Biosensor That Links Membrane Biogenesis to Metabolism" (*Science* 329:1085, 2010). One might object to such a title on two grounds. First, the verb ("Is") is a waste word, in that it can be readily deleted without affecting comprehension. Second, inclusion of the "Is" results in a title that now seems to be a loud assertion. It has a dogmatic ring to it because we are not used to seeing authors present their results in the present tense, for reasons that are discussed in Chapter 30. Rosner (1990, p. 108) gave the name "assertive sentence title" (AST) to this kind of title and presented a number of reasons why such titles should not be used. In particular, ASTs are "improper and imprudent" because "in some cases the AST boldly states a conclusion that is then stated more tentatively in the summary or elsewhere" and "ASTs trivialize a scientific report by reducing it to a one-liner."

The meaning and order of the words in the title are of importance to the potential reader who sees the title in the journal table of contents. But these considerations are equally important to *all* potential users of the literature, including those (probably a majority) who become aware of the paper via secondary sources. Thus, the title should be useful as a label accompanying the paper itself, and it also should be in a form suitable for the machine-indexing systems used by *Chemical Abstracts*, MEDLINE, and others. In short, the terms in the title should be those that highlight the significant content of the paper.

As an aid to readers, journals commonly print *running titles* or *running heads* at the top of each page. Often the title of the journal or book is given at the top of left-facing pages and the article or chapter title is given at the top of right-facing ages (as in this book). Usually, a short version of the title is needed because of space limitations. (The maximum character count is likely to be given in the journal's instructions to authors.) It can be wise to suggest an appropriate running title on the title page of the manuscript.

ABBREVIATIONS AND JARGON

Titles should almost never contain abbreviations, chemical formulas, proprietary (rather than generic) names, jargon, and the like. In designing the title, the author should ask: "How would I look for this kind of information in an index?" If the paper concerns an effect of hydrochloric acid, should the title include the words "hydrochloric acid" or should it contain the much shorter and readily recognizable "HCl"? The answer seems obvious. Most of us would look under "hy" in an index, not under "hc." Furthermore, if some authors used (and journal editors permitted) HCl and others used hydrochloric acid, the user of the bibliographic services might locate only part of the published literature, not noting that additional references are listed under another, abbreviated entry. Actually, the larger secondary services have computer programs that can bring together entries such as deoxyribonucleic acid, DNA, and even ADN (*acide deoxyribonucleique*). However, by far the best rule for authors (and editors) is to avoid abbreviations in titles. And the same rule should apply to proprietary names, jargon, and unusual or outdated terminology.

SERIES TITLES

Many editors are opposed to main title-subtitle arrangements and to hanging titles. The main title-subtitle (series) arrangement was quite common some years ago. (Example: "Studies on Bacteria. IV. Cell Wall of *Staphylococcus aureus*.") Today, many editors believe that it is important, especially for the reader, that each published paper "present the results of an independent, cohesive study; thus, numbered series titles are not allowed" (instructions to authors, *Journal of Bacteriology*). Series papers, in the past, have tended to relate to each other too closely, giving only bits and pieces with each contribution; thus, the reader was severely handicapped unless the whole series could be read consecutively. Furthermore, the series system is annoying to editors because of scheduling problems and delays. (What happens when IV is accepted but III is rejected or delayed in review?) Additional objections are that a series title almost always provides considerable redundancy; the first part (before the roman numeral) is usually so general as to be useless; and the results when the secondary services spin out an index are often unintelligible. (Article titles phrased as questions also can become unintelligible, and so they probably should not be used.)

The hanging title (similar to a series title but with a colon instead of a roman numeral) is considerably better, avoiding some of the problems mentioned above. Some journals, especially in the social sciences (Hartley 2007), seem to favor hanging titles, presumably on the grounds that it is helpful to get the most important words of the title up to the front. (Example: "Global Warming Coverage in the Media: Trends in a Mexico City Newspaper"—*Science Communication* 32:143, 2010). Occasionally, hanging titles may aid the reader, but they may appear pedantic, emphasize the general term rather than a more significant term, necessitate punctuation, and scramble indexes.

Use of a straightforward title does not lessen the need for proper syntax, however, or for the proper form of each word in the title. For example, a title reading "New Color Standard for Biology" would seem to indicate the development of color specifications for use in describing plant and animal specimens. However, in the title "New Color Standard for Biologists" (*Bioscience* 27:762, 1977), the new standard might be useful for study of the taxonomy of biologists, permitting us to separate the green biologists from the blue ones.

CHAPTER 8

How to List the Authors and Addresses

The list of authors establishes accountability as well as credit.

—National Academies Committee
on Science, Engineering,
and Public Policy

THE ORDER OF THE NAMES

"If you have co-authors, problems about authorship can range from the trivial to the catastrophic" (O'Connor 1991, p. 10).

The easiest part of preparing a scientific paper is simply the entering of the bylines: the authors and addresses. Sometimes.

We haven't yet heard of a duel being fought over the order of listing of authors, but there have been instances in which otherwise reasonable, rational colleagues have become bitter enemies solely because they could not agree on whose names should be listed or in what order.

What is the right order? Unfortunately, there are no agreed-upon rules or generally accepted conventions. Some authors, perhaps to avoid arguments among themselves, agree to list their names alphabetically. In the field of mathematics, this practice appears to be standard. Some pairs of researchers who repeatedly collaborate take turns being listed first. If allowed by the journal, sometimes papers include a note indicating that the first two authors contributed equally to the research.

In the past, there was a general tendency to list the head of the laboratory (or, more generally, the head of the research group) as an author whether or not he or she actively participated in the research. Often, the "head" was placed last (second of two authors, third of three, etc.). As a result, the terminal spot this person. Authors should be aware of journal policy in this regard, and they should decide *in advance* which author should serve in this role.

The author who should receive inquiries is called the *corresponding author.* Journals ask that a corresponding author be designated for each paper. The corresponding author typically submits the paper, receives the editor's decision whether to publish it, submits revisions, works with the editorial office after acceptance (for example, by answering questions from the manuscript editor and checking page proofs), and responds to inquiries from readers. The corresponding author should be someone who expects to be readily reachable during and after the publication process. Opinions vary as to whether being a corresponding author is an honor or just a task.

Unless scientists wish to publish anonymously (or as close to it as possible), full names and a full address should be considered obligatory.

CHAPTER 9

How to Prepare the Abstract

I have the strong impression that scientific communication is being seriously hindered by poor quality abstracts written in jargon-ridden mumbo-jumbo.
—Sheila M. McNab

DEFINITION

An abstract should be viewed as a miniature version of the paper. The abstract should provide a *brief* summary of each of the main sections of the paper: introduction, materials and methods, results, and discussion. As Houghton (1975) put it, "An abstract can be defined as a summary of the information in a document."

"A well-prepared abstract enables readers to identify the basic content of a document quickly and accurately, to determine its relevance to their interests, and thus to decide whether they need to read the document in its entirety" (American National Standards Institute 1979b). The abstract should not exceed the length specified by the journal (commonly, 250 words), and it should be designed to define clearly what is dealt with in the paper. Typically, the abstract should be typed as a single paragraph, as in Figure 1. Some journals, however, run "structured" abstracts consisting of a few brief paragraphs, each preceded by a standardized subheading, as in Figure 2. Many people will read the abstract, either in the original journal or as retrieved by computer search.

The abstract should (1) state the principal objectives and scope of the investigation, (2) describe the methods employed, (3) summarize the results, and (4) state the principal conclusions. The importance of the conclusions is indicated by the fact that they are often given three times: once in the

EFFECTS OF SCIENTIFIC-WRITING TRAINING ON KNOWLEDGE AND PUBLICATION OUTPUT

(An Imaginary Study)

Scientists must write to succeed, but few receive training in scientific writing. We studied the effects of a scientific-communication lecture series, alone and combined with feedback on writing, on scientific-communication knowledge and publication performance. During the spring 2005 semester, 50 science Ph.D. students in their last year at Northeast Southwest University were randomly assigned to receive no instruction in scientific writing, attend eight 1-hour lectures on the topic, or attend these lectures and receive feedback from classmates and an instructor on successive parts of a scientific paper they drafted. Members of each group then took a test of scientific-communication knowledge, and the publication output of each group was monitored for 5 years. Members of the groups receiving instruction scored between 80 and 98 percent on the test of scientific-communication knowledge, whereas all but two members of the control group scored below 65 percent. Although on average the group receiving lectures and feedback scored higher than the lecture-only group, the difference was not significant. During the 5-year follow-up, on average the control-group members submitted 6.1 papers to journals and had 4.1 accepted. The corresponding figures for the lecture group were 6.5 and 4.8, and those for the lecture-plus-feedback group were 8.3 and 6.7. Higher proportions of the latter two groups had papers accepted by the first journal to which they were submitted. These findings suggest that instruction in scientific writing, especially if it includes practice and feedback, can increase knowledge of scientific communication and promote publication success.

Figure 1. Abstract (in conventional format) of a fictional scientific paper. This abstract runs slightly less than 250 words and so would comply with typical word limits. Were a real study being reported, the statistical information probably would be more sophisticated. Note that the order of information parallels that in a typical scientific paper.

abstract, again in the introduction, and again (in more detail, probably) in the discussion.

Most or all of the abstract should be written in the past tense, because it refers to work done.

The abstract should never give any information or conclusion that is not stated in the paper. Literature must not be cited in the abstract (except in rare instances, such as modification of a previously published method). Likewise, the abstract should not include or refer to tables and figures.

EFFECTS OF SCIENTIFIC-WRITING TRAINING ON KNOWLEDGE AND PUBLICATION OUTPUT

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Background. Scientists must write to succeed, but few receive training in scientific writing. We studied the effects of a scientific-communication lecture series, alone and combined with feedback on writing, on scientific-communication knowledge and publication performance.

Method. During the spring 2005 semester, 50 science Ph.D. students in their last year at Northeast Southwest University were randomly assigned to receive no instruction in scientific writing, attend eight 1-hour lectures on the topic, or attend these lectures and receive feedback from classmates and an instructor on successive parts of a scientific paper they drafted. Members of each group then took a test of scientific-communication knowledge, and the publication output of each group was monitored for 5 years.

Results. Members of the groups receiving instruction scored between 80 and 98 percent on the test of scientific-communication knowledge, whereas all but two members of the control group scored below 65 percent. Although on average the group receiving lectures and feedback scored higher than the lecture-only group, the difference was not significant. During the 5-year follow-up, on average the control-group members submitted 6.1 papers to journals and had 4.1 accepted. The corresponding figures for the lecture group were 6.5 and 4.8, and those for the lecture-plus-feedback group were 8.3 and 6.7. Higher proportions of the latter two groups had papers accepted by the first journal to which they were submitted.

Conclusion. These findings suggest that instruction in scientific writing, especially if it includes practice and feedback, can increase knowledge of scientific communication and promote publication success.

Figure 2. Structured version of the abstract shown in Figure 1. The two abstracts are the same except for division into paragraphs and inclusion of headings. As noted, the content is fictional.

TYPES OF ABSTRACTS

The preceding rules apply to the abstracts that are used in primary journals and often without change in the secondary services (*Chemical Abstracts*, etc.). This type of abstract is often called an *informative* abstract, and it is designed to condense the paper. It can and should briefly state the problem, the method used to study the problem, and the principal data and conclusions. Often, the abstract supplants the need for reading the full paper; without such abstracts, scientists would not be able to keep up in active areas of research. (However, before citing a paper, you should read it in its entirety, because some abstracts—surely not yours, though!—do not convey an entirely accurate picture of the research.) This is the type of abstract that precedes the body of the paper (thus serving as a "heading") in most journals.

Another common type of abstract is the *indicative* abstract (sometimes called a descriptive abstract). This type of abstract (see Figure 3) is designed to indicate the subjects dealt with in a paper, much like a table of contents, making it easy for potential readers to decide whether to read the paper. However, because of the descriptive rather than substantive nature, it can seldom serve as a substitute for the full paper. Thus, indicative abstracts should not be used as "heading" abstracts in research papers, but they may be used in other types of publications, such as review papers, conference reports, and government reports. Such indicative abstracts are often of great value to reference librarians.

An effective discussion of the various uses and types of abstracts was provided by McGirr (1973, p. 4), whose conclusions are well worth repeating: "When writing the abstract, remember that it will be published by itself, and

TEACHING OF SCIENTIFIC WRITING

(An Imaginary Review Article)

In this article we summarize and discuss the literature on teaching scientific writing. Although we focus mainly on articles in peer-reviewed journals, we also draw on material in professionally oriented magazines and newsletters and in books. First we describe methods used for the literature review, including databases searched, keywords used, and languages and dates included. Then we present information on the history of teaching scientific writing and on instructional designs reported, including single sessions, intensive short courses, and semester-long courses; examples of instruction at specific institutions and under other auspices are noted. Also addressed are the teaching of English-language scientific writing to non-native users of English, the use of distance instruction in teaching scientific writing, issues in scientific-writing instruction, and current trends in the field. Finally, we identify topics on which further research appears advisable. Supplementary materials include annotated lists of textbooks and websites useful in teaching scientific writing.

Figure 3. Indicative (descriptive) abstract of a fictional review article. This abstract runs about 150 words. Like a table of contents, it lists topics but does not state what is said about them.

should be self-contained. That is, it should contain no bibliographic, figure, or table references. . . . The language should be familiar to the potential reader. Omit obscure abbreviations and acronyms. Write the paper before you write the abstract, if at all possible."

Unless a long term is used several times within an abstract, do not abbreviate the term. Wait and introduce the appropriate abbreviation at first use in the text (probably in the introduction).

ECONOMY OF WORDS

Occasionally, a scientist omits something important from the abstract. By far the most common fault, however, is the inclusion of extraneous detail.

A scientist once had some terribly involved theory about the relation of matter to energy. He then wrote a terribly involved paper. However, the scientist, knowing the limitations of editors, realized that the abstract of his paper would have to be short and simple if the paper was to be judged acceptable. So, he spent hours and hours honing his abstract. He eliminated word after word until, finally, all of the verbiage had been removed. What he was left with was the shortest abstract ever written: "$E = mc^2$."

Today, most scientific journals print a heading abstract with each paper. It generally is printed (and should be submitted) as a single paragraph. Because the abstract precedes the paper itself, and because the editors and reviewers like a bit of orientation, the abstract is almost always the first part of the manuscript read during the review process. Therefore, it is of fundamental importance that the abstract be written clearly and simply. If you cannot make a good impression in your abstract, your cause may be lost. Very often, the reviewer may be perilously close to a final judgment of your manuscript after reading the abstract alone. This could be because the reviewer has a short attention span (often the case). However, if by definition the abstract is simply a very short version of the whole paper, it is only logical that the reviewer will often reach a preliminary conclusion, and that conclusion is likely to be the correct one. Usually, a good abstract is followed by a good paper; a poor abstract is a harbinger of woes to come.

Because a heading abstract is required by most journals and because a meeting abstract is a requirement for participation in a great many national and international meetings (participation sometimes being determined on the basis of submitted abstracts), scientists should master the fundamentals of abstract preparation.

When writing the abstract, examine every word carefully. If you can tell your story in 100 words, do not use 200. Economically and scientifically, it doesn't make sense to waste words. The total communication system can afford only so much verbal abuse. Of more importance to you, the use of clear, significant words will impress the editors and reviewers (not to mention readers), whereas the use of abstruse, verbose constructions might well contribute to a check in the "reject" box on the review form.

One experienced teacher of scientific writing sometimes told a story designed to point up the essentials of good abstract writing. He instructed his students to take down only the *key* points in the story, which of course is the key to writing good abstracts.

The story goes like this: One night a symphony orchestra was scheduled to play Beethoven's famous Ninth Symphony. Before the performance, the bass viol players happened to be chatting among themselves, and one of the bass players reminded the others that there is a long rest for the bass players toward the conclusion of Beethoven's Ninth. One bassist said, "Tonight, instead of sitting on the stage looking dumb all that time, why don't we sneak off the stage, go out the back door, go to the bar across the street, and belt down a few?" They all agreed. That night, when "rest" time came, they indeed snuck off the stage, went to the bar, and knocked back about four double scotches each. One bass player said, "Well, it's about time we headed back for the finale." Whereupon another bassist said, "Not to worry. After we decided to do this, I went up to the conductor's stand and, at the place in the conductor's score where our rest ends, I tied a bunch of string around his score. It will take him a few minutes to untie those knots. Let's have another." And they did.

At this point, the teacher told the students, "Now, this story has reached a very dramatic point. If you have put down the essentials, as you would in a good abstract, here is what you should have: It's the last of the Ninth, the score is tied, and the basses are loaded."

CHAPTER 10

How to Write the Introduction

A bad beginning makes a bad ending.

—Euripides

SUGGESTED RULES

Now that we have the preliminaries out of the way, we come to the paper itself. Some experienced writers prepare their title and abstract after the paper is written, even though by placement these elements come first. You should, however, have in mind (if not on paper or in the computer) a provisional title and an outline of the paper you propose to write. You should also consider the level of the audience you are writing for, so that you will have a basis for determining which terms and procedures need definition or description and which do not. If you do not have a clear purpose in mind, you might go writing off in six directions at once.

It is wise to begin writing the paper while the work is still in progress. This makes the writing easier because everything is fresh in your mind. Furthermore, the writing process itself is likely to point to inconsistencies in the results or perhaps to suggest interesting sidelines that might be followed. Thus, start the writing while the experimental apparatus and materials are still available. If you have coauthors, it is wise to write up the work while they are still available to consult.

The first section of the text proper should, of course, be the introduction. The purpose of the introduction should be to supply sufficient background information to allow the reader to understand and evaluate the results of the present study without needing to refer to previous publications on the topic. The introduction should also provide the rationale for the present study. Above all, you should state briefly and clearly your purpose in writing the paper. Choose references carefully to provide the most important background information. Much of the introduction should be written in present tense, because you will be referring primarily to your problem and the established knowledge relating to it at the start of your work.

Suggested rules for a good introduction are as follows: (1) The introduction should present first, with all possible clarity, the nature and scope of the problem investigated. (2) It should briefly review the pertinent literature to orient the reader. (3) It should state the method of the investigation. If deemed necessary, the reasons for the choice of a particular method should be stated. (4) It should state the principal results of the investigation. (5) It should state the principal conclusions suggested by the results. Do not keep the reader in suspense; let the reader follow the development of the evidence. An O. Henry surprise ending might make good literature, but it hardly fits the mold of the scientific method.

To expand on that last point: Many authors, especially beginning authors, make the mistake of holding back their more important findings until late in the paper. In extreme cases, authors have sometimes omitted important findings from the abstract, presumably in the hope of building suspense while proceeding to a well-concealed, dramatic climax. However, this is a silly gambit that, among knowledgeable scientists, goes over like a double negative at a grammarians' picnic. Basically, the problem with the surprise ending is that the readers become bored and stop reading long before they get to the punch line. "Reading a scientific article isn't the same as reading a detective story. We want to know from the start that the butler did it" (Ratnoff 1981, p. 96).

REASONS FOR THE RULES

The first three rules for a good introduction need little discussion, being reasonably well accepted by most scientist-writers, even beginning ones. It is important to keep in mind, however, that the purpose of the introduction is to introduce (the paper). Thus, the first rule (definition of the problem) is the cardinal one. And, obviously, if the problem is not stated in a reasonable, understandable way, readers will have no interest in your solution. Even if the reader labors through your paper, which is unlikely if you haven't presented the problem in a meaningful way, he or she will be unimpressed with the brilliance of your solution. In a sense, a scientific paper is like other types of journalism. In the introduction you should have a "hook" to gain the reader's attention. Why did you choose *that* subject, and why is it *important?*

The second and third rules relate to the first. The literature review and choice of method should be presented in such a way that the reader will understand what the problem was and how you tried to resolve it.

These three rules then lead naturally to the fourth and fifth, the statement of principal results and conclusions, which should be the capstone of the introduction. This road map from problem to solution is so important that a bit of redundancy with the abstract is often desirable.

SOME EXCEPTIONS

In some research areas and journals, scientific papers typically follow only the first three rules. Thus, when looking at papers in your target journal as models, see whether their introductions state the results and conclusions. If they do not, you probably should not do so in your introduction.

Also, in some fields, the introduction commonly has a "funnel" shape, moving from broad and general to narrow and specific. For example, in the introduction you may begin with information on the importance of the overall topic being addressed, next summarize knowledge about an aspect of the topic, then identify an unresolved question about that aspect, and finally say how the current research addressed the question. (See Figure 4.) The approach resembles one you might use when a visitor comes to your lab and you first provide background information and then show what you have been doing. In essence, the reader of your paper is visiting your research venue; an introduction thus structured can provide a helpful and hospitable welcome.

CITATIONS AND ABBREVIATIONS

If you have previously published a preliminary note or abstract of the work, you should mention this (with the citation) in the introduction. If closely related papers have been or are about to be published elsewhere, you should say so in the introduction, customarily at or near the end. Such references help to keep the literature neat and tidy for those who must search it.

In addition to the preceding rules, keep in mind that your paper may well be read by people outside your narrow specialty. Therefore, in general you should define in the introduction any specialized terms or abbreviations that you intend to use. By doing so, you can prevent confusion such as one of us

INTRODUCTION TO AN IMAGINARY PAPER

Scientists must write to succeed, but few receive training in scientific writing. According to recent surveys, only 9 percent of scientists in the United States,[1] 5 percent of scientists in China,[2] and 3 to 12 percent of scientists attending recent international conferences[3-5] have taken a course in scientific writing. Even when briefer forms of instruction, such as workshops, are included, only about 25 percent of U.S. scientists have received formal instruction in scientific writing.[1] Discussions at a recent roundtable[6] suggest that the figure tends to be lower in other countries.

Further, relatively little information exists regarding the effectiveness of such instruction. One study[7] indicated that compared with peers without such instruction, postdoctoral fellows who had taken a scientific-writing course as graduate students felt more confident of their scientific-writing abilities and received more comments of "well written" from peer reviewers. Another study[8] suggested that the time from submission to final acceptance tended to be shorter for papers by authors who had taken a course in scientific writing. However, a third study[9] found no difference in quality of scientific papers written by early-career scientists who had completed a weeklong workshop on scientific writing and those who had spent the time vacationing at a national park. The literature appears to contain little, if anything, on effects of scientific-writing instruction on knowledge or on number of publications. Likewise, it contains little or nothing on the relative effects of different forms of scientific-writing instruction.

To help address these gaps, we compared outcomes in advanced graduate students randomly assigned to receive no instruction in scientific writing, to attend a lecture series on the topic, and to attend the lecture series and receive feedback on a draft of a scientific paper. We then tested scientific-communication knowledge and monitored publication output for 5 years. Outcome measures included number of papers submitted, number of papers accepted for publication, and time from initial acceptance to publication.

Figure 4. Introduction to an imaginary paper on effects of scientific-writing training. This introduction, which runs about 300 words, follows the "funnel format," moving from general to specific. All content in this introduction is fictional.

experienced in the following situation: An acquaintance who was a law judge kept referring to someone as a GC. Calling a lawyer a gonococcus (gonorrhea-causing bacterium) seemed highly unprofessional. It turned out, however, that in law, unlike in medicine, GC stands for "general counsel."

CHAPTER 11

How to Write the Materials and Methods Section

The greatest invention of the nineteenth century was the invention of the method of invention.

—A. N. Whitehead

PURPOSE OF THE SECTION

In the first section of the paper, the introduction, you stated (or should have) the methodology employed in the study. If necessary, you also defended the reasons for your choice of a particular method over competing methods.

Now, in "Materials and Methods" (also designated in some cases by other names, such as "Experimental Procedures"), you must give the full details. Most of this section should be written in the past tense. The main purpose of the materials and methods section is to describe (and if necessary, defend) the experimental design and then provide enough detail so that a competent worker can repeat the experiments. Other purposes include providing information that will let readers judge the appropriateness of the experimental methods (and thus the probable validity of the findings) and that will permit assessment of the extent to which the results can be generalized. Many (probably most) readers of your paper will skip this section, because they already know (from the introduction) the general methods you used, and they probably have no interest in the experimental detail. However, careful writing of this section is critically important because the cornerstone of the scientific method requires that your results, to be of scientific merit, must be reproducible; and, for the results to be adjudged reproducible, you must provide the basis for repetition of the experiments by others. That experiments are unlikely to be reproduced is beside the point; the potential for reproducing the same or similar results must exist, or your paper does not represent good science.

When your paper is subjected to peer review, a good reviewer will read the materials and methods section carefully. If there is serious doubt that your experiments could be repeated, the reviewer will recommend rejection of your manuscript no matter how awe-inspiring your results.

MATERIALS

For materials, include the exact technical specifications and quantities and source or method of preparation. Sometimes it is even necessary to list pertinent chemical and physical properties of the reagents used. In general, avoid the use of trade names; use of generic or chemical names is usually preferred. This approach avoids the advertising inherent in the trade name. Besides, the nonproprietary name is likely to be known throughout the word, whereas the proprietary name may be known only in the country of origin. However, if there are known differences among proprietary products, and if these differences might be critical, then use of the trade name, plus the name of the manufacturer, is essential. When trade names, which are usually registered trademarks, are used, they should be capitalized (Teflon, for example) to distinguish them from generic names. Normally, the generic description should immediately follow the trademark; for example, one would refer to Kleenex facial tissues. It is not necessary to include trademark symbols (such as ® and ™).

Experimental animals, plants, and microorganisms should be identified accurately, usually by genus, species, and strain designations. Sources should be listed and special characteristics (age, sex, genetic and physiological status) described. If human subjects were used, the criteria for selection should be described, and an "informed consent" statement should be included in the manuscript. Likewise, if human or animal subjects were used, approval by the appropriate committee should be noted.

Because the value of your paper (and your reputation) can be damaged if your results are not reproducible, you must describe research materials with great care. Be sure to examine the instructions to authors of the journal to which you plan to submit the manuscript, because important specifics are often detailed there. Below is a carefully worded statement applying to cell lines and reagents. It is taken from the information for authors of *In Vitro Cellular & Developmental Biology—Animal* (known for short as *In Vitro Animal*), a journal of the Society for In Vitro Biology.

> The source of cells utilized, species, sex, strain, race, age of donor, and whether primary or established should be clearly indicated. The name, city, and state or country of the source of reagents should be stated within parentheses when first cited. Specific tests used for verification of cell lines and novel reagents should be identified. Specific tests for the presence of mycoplasmal contamination of cell lines are recommended. If these tests were not performed, this fact should be clearly stated. Other data relating to unique biological, biochemical, and/or immunological markers should also be included if available. Publication of results in *In Vitro Animal* is based on the principle that results must be verifiable. Authors are expected to make unique reagents available to qualified investigators. Authors deriving or using cell lines are encouraged to follow the UKCCCR [United Kingdom Coordinating Committee on Cancer Research] Guidelines for the Use of Cell Lines in Cancer Research in respect to validation of identity and infection-free cultures.

METHODS

For methods the usual order of presentation is chronological. Obviously, however, related methods should be described together, and straight chronological order cannot always be followed. For example, even if a particular assay was not done until late in the research, the assay method should be described along with the other assay methods, not by itself in a later part of the materials and methods section.

HEADINGS

The materials and methods section often has subheadings. To see whether subheadings would indeed be suitable—and, if so, what types are likely to be appropriate—look at analogous papers in your target journal. When possible, construct subheadings that "match" those to be used in the results section. The writing of both sections will be easier if you strive for internal consistency, and the reader will be able to grasp quickly the relationship of a particular method to the related results.

MEASUREMENTS AND ANALYSIS

Be precise. Methods are similar to cookbook recipes. If a reaction mixture was heated, give the temperature. Questions such as "how" and "how much" should be precisely answered by the author and not left for the reviewer or the reader to puzzle over.

Statistical analyses are often necessary, but you should feature and discuss the data, not the statistics. Generally, a lengthy description of statistical methods indicates that the writer has recently acquired this information and believes that the readers need similar enlightenment. Ordinary statistical methods generally should be used without comment; advanced or unusual methods may require a literature citation. In some fields, statistical methods or statistical software customarily is identified at the end of the materials and methods section.

And again, be careful of your syntax. A recent manuscript described what could be called a disappearing method. The author stated, "The radioactivity in the tRNA region was determined by the trichloroacetic acid-soluble method of Britten et al." And then there is the painful method: "After standing in boiling water for an hour, examine the flask."

NEED FOR REFERENCES

In describing the methods of the investigations, you should give (or direct readers to) sufficient details so that a competent worker could repeat the experiments. If your method is new (unpublished), you must provide *all* of the needed detail. If, however, the method has been published in a journal, the literature reference should be given. For a method well known to readers, only the literature reference is needed. For a method with which readers might not be familiar, a few words of description tend to be worth adding, especially if the journal in which the method was described might not be readily accessible.

If several alternative methods are commonly employed, it is useful to identify your method briefly as well as to cite the reference. For example, it is better to state "cells were broken by ultrasonic treatment as previously described (9)" than to state "cells were broken as previously described (9)."

TABLES AND FIGURES

When large numbers of microbial strains or mutants are used in a study, prepare strain tables identifying the source and properties of mutants, bacteriophages, plasmids, etc. The properties of a number of chemical compounds can also be presented in tabular form, often to the benefit of both the author and the reader. Tables can be used for other such types of information.

A method, strain, and the like used in only one of several experiments reported in the paper generally should be described in the results section. If brief enough, it may be included in a table footnote or figure legend if the journal allows.

Figures also can aid in presenting methods. Examples include flow charts of experimental protocols and diagrams of experimental apparatus.

CORRECT FORM AND GRAMMAR

Do *not* make the common error of mixing some of the results in this section. There is only one rule for a properly written materials and methods section: Enough information must be given so that the experiments could be reproduced by a competent colleague.

A good test, by the way (and a good way to avoid rejection of your manuscript), is to give a copy of your finished manuscript to a colleague and ask if he or she can follow the methodology. It is quite possible that in reading about your materials and methods, your colleague will pick up a glaring error that you missed simply because you were too close to the work. For example, you might have described your distillation apparatus, procedure, and products with infinite care, and then inadvertently neglected to define the starting material or to state the distillation temperature.

Mistakes in grammar and punctuation are not always serious; the meaning of general concepts, as expressed in the introduction and discussion, can often survive a bit of linguistic mayhem. In materials and methods, however, exact and specific items are being dealt with and precise use of English is a must. Even a missing comma can cause havoc, as in this sentence: "Employing a straight platinum wire rabbit, sheep and human blood agar plates were inoculated . . ." That sentence was in trouble right from the start, because the first word is a dangling participle. Comprehension was not totally lost, however, until the author neglected to put a comma after "wire."

Authors often are advised, quite rightly, to minimize use of passive voice. However, in the materials and methods section—as in the current paragraph—passive voice often can validly be used, for although what was done must be specified, who did it is often irrelevant. Thus, you may write, for example, "Mice were injected with . . ." rather than "I injected the mice with . . . ," "A technician injected the mice with . . . ," or "A student injected the mice with . . . ." Alternatively, you may say, for example, "We injected . . . ," even if a single member of the team did that part of the work. (Although belief persists that journals prohibit use of first person, many journals permit use of "I" and "we.")

Because the materials and methods section usually gives short, discrete bits of information, the writing sometimes becomes telescopic; details essential to the meaning may then be omitted. The most common error is to state the action without, when necessary, stating the agent of the action. In the sentence "To determine its respiratory quotient, the organism was . . . ," the only stated agent of the action is "the organism," and we doubt that the organism was capable of making such a determination. Here is a similar sentence: "Having completed the study, the bacteria were of no further interest." Again, we doubt that the bacteria "completed the study"; if they did, their lack of "further interest" was certainly an act of ingratitude.

"Blood samples were taken from 48 informed and consenting patients . . . the subjects ranged in age from 6 months to 22 years" (*Pediatr. Res.* 6:26, 1972). There is no grammatical problem with that sentence, but the telescopic writing leaves the reader wondering just how the 6-month-old infants gave their informed consent.

And, of course, always watch for spelling errors, both in the manuscript and in the proofs. We are not astronomers, but we suspect that a word is misspelled in the following sentence: "We rely on theatrical calculations to give the lifetime of a star on the main sequence" (*Annu. Rev. Astron. Astrophys.* 1:100, 1963). Although they might have been done with a flourish, presumably the calculations were theoretical, not theatrical.

Be aware that a spell-checker can introduce such errors and therefore cannot substitute for careful proofreading. One recent example: a spell-checker's conversion of "pacemakers in dogs" to "peacemakers in dogs." We have known some dogs that could benefit from peacemakers, but we rightly suspected that this wording was not intended in writing about canine cardiology.

CHAPTER 12

How to Write the Results

Results! Why, man, I have gotten a lot of results. I know several thousand things that won't work.

—Thomas A. Edison

CONTENT OF THE RESULTS

So now we come to the core of the paper, the data. This part of the paper is called the results section.

Contrary to popular belief, you shouldn't start the results section by describing methods that you inadvertently omitted from the materials and methods section.

There are usually two ingredients of the results section. First, you should give some kind of overall description of the experiments, providing the big picture without repeating the experimental details previously provided in materials and methods. Second, you should present the data. Your results should be presented in the past tense. (See "Tense in Scientific Writing" in Chapter 30.)

Of course, it isn't quite that easy. How do you present the data? A simple transfer of data from laboratory notebook to manuscript will hardly do.

Most importantly, in the manuscript you should present representative data rather than endlessly repetitive data. The fact that you could perform the same experiment 100 times without significant divergence in results might be of considerable interest to your major professor, but editors, not to mention readers, prefer a little bit of predigestion. Aaronson (1977, p. 10) said it another way: "The compulsion to include everything, leaving nothing out, does not prove that one has unlimited information; it proves that one lacks discrimination." Exactly the same concept, and it is an important one, was stated almost a century earlier by John Wesley Powell, a geologist who served as president of the American Association for the Advancement of Science in 1888. In Powell's words: "The fool collects facts; the wise man selects them."

HOW TO HANDLE NUMBERS

If one or only a few determinations are to be presented, they should be treated descriptively in the text. Repetitive determinations should be given in tables or graphs.

Any determinations, repetitive or otherwise, should be meaningful. Suppose that, in a particular group of experiments, a number of variables were tested (one at a time, of course). Those variables that affect the reaction become determinations or data and, if extensive, are tabulated or graphed. Those variables that do not seem to affect the reaction need not be tabulated or presented; however, it is often important to define even the negative aspects of your experiments. It is often good insurance to state what you did *not* find under the conditions of your experiments. Someone else very likely may find different results under different conditions.

If statistics are used to describe the results, they should be meaningful statistics. Erwin Neter, who was editor in chief of *Infection and Immunity*, told a classic story to emphasize this point. He referred to a paper that reputedly read: "33 1/3% of the mice used in this experiment were cured by the test drug; 33 1/3% of the test population were unaffected by the drug and remained in a moribund condition; the third mouse got away."

STRIVE FOR CLARITY

The results should be short and sweet, without verbiage. Mitchell (1968) quoted Einstein as having said, "If you are out to describe the truth, leave elegance to the tailor." Although the results section is the most important part, it is often the shortest, particularly if it is preceded by a well-written materials and methods section and followed by a well-written discussion.

The results need to be clearly and simply stated because it is the results that constitute the new knowledge that you are contributing to the world. The earlier parts of the paper (introduction, materials and methods) are designed to tell why and how you got the results; the later part of the paper (discussion) is designed to tell what they mean. Obviously, therefore, the whole paper must stand or fall on the basis of the results. Thus, the results must be presented with crystal clarity.

AVOID REDUNDANCY

Do not be guilty of redundancy in the results. The most common fault is the repetition in words of what is already apparent to the reader from examination of the figures and tables. Even worse is the actual presentation, in the text, of all or many of the data shown in the tables or figures. This grave sin is committed so frequently that it is commented on at length, with examples, in the chapters on how to prepare tables and illustrations (Chapters 16 and 17).

Do not be verbose in citing figures and tables. Do not say, "It is clearly shown in Table 1 that nocillin inhibited the growth of *N. gonorrhoeae*." Say, "Nocillin inhibited the growth of *N. gonorrhoeae* (Table 1)." The latter format has multiple benefits. Because it is briefer, it helps authors comply with journals' word limits. It also is more readable. And it directs attention to what is most important: the findings, not the table or figure.

Some writers go too far in avoiding verbiage, however. Such writers often fail to provide clear antecedents for pronouns, especially "it." Here is an item from a medical manuscript: "The left leg became numb at times and she walked it off. . . . On her second day, the knee was better, and on the third day it had completely disappeared." The antecedent for both "its" is presumably "the numbness," but the wording in both instances seems a result of dumbness.

A SUPPLEMENT ON SUPPLEMENTARY MATERIAL ONLINE

Increasingly, journals are electronically posting material supplementary to papers being published. Although sometimes this material regards methods, most commonly it provides information about the results. For example, additional data may be posted, or additional tables and figures may be provided online. Whether authors may submit such supplementary material, and if so how, varies among journals. Also, norms regarding what supplementary materials to provide online vary among research fields. If you think that providing supplementary material for online posting would be desirable, consult the instructions to authors of your target journal. If possible, also see what papers analogous to yours have done in this regard. Keep in mind, too, that the journal editor may ask you to place some of your material in an online supplement.

CHAPTER 13

How to Write the Discussion

It is the fault of our rhetoric that we cannot strongly state one fact without seeming to belie some other.

—Ralph Waldo Emerson

DISCUSSION AND VERBIAGE

The discussion (which some journals term a comment, especially for short papers) is harder to define than the other sections. Thus, it is usually the hardest section to write. And, whether you know it or not, *many* papers are rejected by journal editors because of a faulty discussion, even though the data of the paper might be both valid and interesting. Even more likely, the true meaning of the data may be completely obscured by the interpretation presented in the discussion, again resulting in rejection.

Many, if not most, discussion sections are too long and verbose. As Doug Savile said, "Occasionally, I recognize what I call the squid technique: the author is doubtful about his facts or his reasoning and retreats behind a protective cloud of ink" (*Tableau*, September 1972). Another reason some discussions are long and hard to follow is that many authors think they must avoid first person. If you mean "I found that . . ." or "We conclude that . . . ," say so. Try to avoid wordier, and sometimes more ambiguous, constructions such as "It was found in the present investigation that . . ." and "It is concluded that."

Some discussion sections remind one of the diplomat, described by Allen Drury in *Advise and Consent* (Garden City, NY: Doubleday, 1959, p. 47), who characteristically gave "answers which go winding and winding off through the interstices of the English language until they finally go shimmering away altogether and there is nothing left but utter confusion and a polite smile."

COMPONENTS OF THE DISCUSSION

What are the essential features of a good discussion? The main components will be provided if the following injunctions are heeded.

1. Try to present the principles, relationships, and generalizations shown by the results. And bear in mind, in a good discussion, *you discuss—you do not recapitulate*—the results.
2. Point out any exceptions or any lack of correlation and define unsettled points. Never take the high-risk alternative of trying to cover up or fudge data that do not quite fit.
3. Show how your results and interpretations agree (or contrast) with previously published work.
4. Don't be shy; discuss the theoretical implications of your work, as well as any possible practical applications.
5. State your conclusions as clearly as possible.
6. Summarize your evidence for each conclusion. Or, as the wise old scientist will tell you, "Never assume anything except a 4 percent mortgage."

Much as the methods and the results should correspond to each other, the introduction and the discussion should function as a pair. At least implicitly, the introduction should have posed one or more questions. The discussion should indicate what the findings say about the answers. Failure to address the initial questions commonly afflicts discussions. Be sure the discussion answers what the introduction asked.

Whereas the content of the introduction commonly moves from the general topic to your specific research, in sort of a funnel format, the discussion tends to do largely the reverse, much like an inverted funnel. For example, a well-structured discussion may first restate the main findings, then discuss how they relate to findings of previous research, then note implications and applications, and perhaps then identify unanswered questions well suited for future research. In the introduction, you invited readers into your research venue; in the discussion, you usher them out, now well informed about your research and its meaning.

FACTUAL RELATIONSHIPS

In simple terms, the primary purpose of the discussion is to show the relationships among observed facts. To emphasize this point, the story may be told about the biologist who trained a flea.

After training the flea for many months, the biologist was able to get a response to certain commands. The most gratifying of the experiments was the one in which the professor would shout the command "Jump," and the flea would leap into the air each time the command was given.

The professor was about to submit this remarkable feat to posterity via a scientific journal, but he—in the manner of the true scientist—decided to take his experiments one step further. He sought to determine the location of the receptor organ involved. In one experiment, he removed the legs of the flea, one at a time. The flea obligingly continued to jump upon command, but as each successive leg was removed, its jumps became less spectacular. Finally, with the removal of its last leg, the flea remained motionless. Time after time the command failed to get the usual response.

The professor decided that at last he could publish his findings. He set pen to paper and described in meticulous detail the experiments executed over the preceding months. His conclusion was one intended to startle the scientific world: *When the legs of a flea are removed, the flea can no longer hear.*

Claude Bishop, the dean of Canadian science editors, told a similar story. A science teacher set up a simple experiment to show her class the danger of alcohol. She set up two glasses, one containing water, the other containing gin. Into each she dropped a worm. The worm in the water swam merrily around. The worm in the gin quickly died. "What does this experiment prove?" she asked. A student from the back row piped up: "It proves that if you drink gin you won't have worms."

NOTING STRENGTHS AND LIMITATIONS

The discussion is a place to note substantial strengths and limitations of research being reported. Some authors feel awkward about including such content. However, doing so can aid readers, and it can help show editors and referees (peer reviewers) that your work is publishable.

Some authors consider it immodest to note strengths of their work—for example, superior experimental techniques, large sample size, or long follow-up. However, such information can aid readers in determining how definitive the findings are. It also can help persuade peer reviewers and editors that your work deserves publication.

What if research had significant limitations—such as difficulties with a technique, a relatively small sample size, or relatively short follow-up? Some authors might try to hide such limitations. However, doing so runs counter to the openness that should characterize science. And astute reviewers, editors, or readers might well notice the limitations—and assume, either to themselves or in writing, that you were too naïve to notice them. It is better, therefore, to identify substantial limitations yourself. In doing so, you may be able to discuss what impact, if any, the limitations are likely to have on the conclusions that can be drawn.

Not every discussion needs to discuss strengths or limitations of the research. However, if research has strengths or limitations major enough to be worthy of note, consider addressing them in the discussion.

SIGNIFICANCE OF THE PAPER

Too often, the *significance* of the results is not discussed or not discussed adequately. If the reader of the paper finds himself or herself asking "So what?" after reading the discussion, the chances are that the author became so engrossed with the trees (the data) that he or she didn't really notice how much sunshine had appeared in the forest.

The discussion should end with a short summary or conclusion regarding the significance of the work. (In some journals, papers include a separate conclusion section.) We like the way Anderson and Thistle (1947) said it: "Finally, good writing, like good music, has a fitting climax. Many a paper loses much of its effect because the clear stream of the discussion ends in a swampy delta." Or, in the words of T. S. Eliot, many scientific papers end "Not with a bang but a whimper."

DEFINING SCIENTIFIC TRUTH

In showing the relationships among observed facts, you do not need to reach cosmic conclusions. Seldom will you be able to illuminate the whole truth; more often, the best you can do is shine a spotlight on one area of the truth. Your one area of truth can be illuminated by your data; if you extrapolate to a bigger picture than that shown by your data, you may appear foolish to the point that even your data-supported conclusions are cast into doubt.

One of the more meaningful thoughts in poetry was expressed by Sir Richard Burton in *The Kasidah:*

> All Faith is false, all Faith is true;
> Truth is the shattered mirror strown
> In myriad bits; while each believes
> His little bit the whole to own.

So exhibit your little piece of the mirror, or shine a spotlight on one area of the truth. The "whole truth" is a subject best left to the ignoramuses, who loudly proclaim its discovery every day.

When you describe the meaning of your little bit of truth, do it simply. The simplest statements evoke the most wisdom; verbose language and fancy technical words are used to convey shallow thought.