1. COMMUNICATING SCIENCE

If one tells the truth, one is sure, sooner or later,
to be found out. —OSCAR WILDE

First Things

Science exists because scientists are writers and speakers. We know this, if only intuitively, from the very moment we embark on a career in biology, physics, or geology. As a shared form of knowledge, scientific understanding is inseparable from the written and spoken word. There are no boundaries, no walls, between the doing of science and the communication of it; communicating *is* the doing of science. If data falls in the forest, and no one hears or sees or it . . . Research that never sees the dark of print remains either hidden or virtual or nonexistent. Publication and public speaking are how scientific work gains a presence, a shared reality in the world.

These basic truths form a starting point. As scientists, we are scholars too, steeped in learning, study, and, yes, competitive fellowship. Communicating is our life's work—it is what determines our presence and place in the universe of professional endeavor. And so we must accept the duties, as well as the demands and urges (and, fortunately or unfortunately, the responsibilities) of authorship. But aside from noble sentiment, there are other reasons for being able to communicate well with our intellectual brethren.

No one who aspires to a scientific career can afford to overlook the practical implications of what has just been said. The ability to write and

speak effectively will determine, in no uncertain terms, the perceived importance and validity of your work. To a large degree, your reputation will rest on your ability to communicate. The reason to improve your skill in this area, therefore, is not to please English teachers past and present (though these may well haunt us till we shed our mortal coil). It is to gain something very real in the professional world, something of advantage. To communicate well is to engage in self-interest. Another way of saying this is that writing and speaking intelligibly are required forms of professional competence—nothing less.

Contrary to what you may feel, however, based on your own experience and the stories of others, this situation is not a fatal one. Creating and sharing knowledge are truly profound but also eminently performable acts. Indeed, they are among the highest achievements of which human beings are capable. Every time you put finger to keyboard, step up to the podium, or clear your throat in front of a class, you become a full participant in what has clearly become humankind's most powerful domain of intellectual enterprise.

The purpose of this guide is to help you, the scientist, deal competently, even eloquently, with your role as an author. My intent is to aid you in learning how to feel at home with, and even take significant pride in, the communicating you will do as a member of the greater scientific community. This can be done, as it happens, without torture or torment, golden rules or iron systems. What it does require, among other things, is patience, a willingness to learn from others, and a certain way of looking at authorship.

The Importance of Attitude

Writing, we know, does not always come easily to scientists. Innumerable tales can be told of brilliant researchers whose papers would blind the eye of a first-year composition instructor. Yet, in reality, good writing rarely comes easily to *anyone*, in *any* discipline, whether quantum mechanics or art history. Writing is aptly called a skill, or, more accurately, a collection of skills. It is never entirely mechanical and always involves a level of emotional engagement, as well as forbearance and discipline. The Japanese have an excellent proverb for what it takes to learn a skill: "Ishi no ue ni, san nen." Three years, standing on a rock.

I'm not suggesting that we try this (one to two years, with time off for good behavior, should be plenty). But it points in a certain direction. What has our training, as scientists, been like in this area? In fact, a major difference between the humanities and sciences is that composing, critiquing, and revising papers forms a central part of learning in the former, while in the sciences it does not. Moreover, immersing oneself in eloquent writing of the past is also prominent in humanities training, whereas scientific instruction tends to avoid this sort of thing almost entirely. We don't read Newton (or much of him) in a basic physics class, Linnaeus in a botany course, Lavoisier or Lyell in a chemistry or geology curriculum. Why is this so? The reasons are complex, and have much to do with the recent history of science. But the effects are clear: good writing is something that scientists are supposed to pick up, either from a course or two in technical writing while in school, or through osmosis after entering the caffeine-ridden world of professional research.

If formal communication can be intimidating for scientists and engineers, what is the best way to help gain back the upper hand? Much begins with how one thinks about writing in particular and about scientific language in general. To communicate well, you need to feel at least some degree of *control* over the language you are using. This means a basic awareness that you, the writer, are taking words and images and creating something out of them. It also means an understanding that you are doing this by employing certain forms and structures toward the goal of persuading—telling a story to—a very particular kind of audience.

Too often in science we have the feeling that language is our opponent, something we have to wrestle with and subdue. Technical speech can seem like something hardened and formal that we have to obey, that predetermines a great deal of what we can and cannot say. There is a drop of truth here; scientific writing *is* generally flat, unromantic, heavily reliant on preexisting technical terms and phrases. Journal editors are unlikely to smile favorably at literary turns of phrase, passionate outbursts, or fanfares to the gods of invention. Yet this hardly describes the whole of the matter. Science may sound anonymous to the ear, but it is fully human and personal to the touch. The calm, declarative "voice" of technical speech is something we must make anew, every time, through a host of choices, a number of which are actually quite flexible. If we look closely enough, we can find many avenues where personal eloquence may be put to practical use. The creative and the individual have a very important dimension in our writing (I'll say more about this in chapter 4).

At the same time, we scientists have certain advantages over our (dis-

tant?) cousins in the humanities. Some of the same aspects that make our language seem flat and formal work in our favor. Abundant use of technical words and phrases does, in fact, mean that pieces of our discourse are prefabricated. There are more moments, that is, during the composition of any paper when a series of words flow easily from the fingers into place, as if by automation. This is not a sign of cybernetic rebirth, but actually something close to the opposite: an intuitive sense of when this is needed or possible. How do we acquire this? The answer is probably not very shocking—by internalizing the discourse of our subject and field. Such can come from long years of reading and reciting (at meetings) the relevant literature, until it becomes second speech. But there are other ways that require far less time, that graduate students can use. I will go over them in chapter 3. The point here is that scientists shouldn't feel that writing is a lonely chore or errand in the wilderness. It is communal at every step and comes with help.

Much begins and ends with attitude, therefore. Reasonably confident authors transfer their sense of self to the reader. Their science tends to be effective, less hesitant. If, however, you are terrified of writing, it is likely that your writing will terrify others (or worse, inspire humor). Conversely, if you view the composition of technical papers as an unbounded creative exercise, with enthrallment as its goal, you will meet a quick and scarlet end at the hands of the first editor you encounter This book has been written to protect you from both fates.

The Existing Literature on Technical Communication: A Brief Warning

I would be remiss, both as a scientist and as a writer, if I did not include some pointed words about my competitors. In technical terms, this means a "review of the existing literature."

Many manuals and guides have been written over the years to fill the training gap in scientific writing and speaking. As might be expected, the results are (to put it diplomatically) variable. There are many excellent thoughts scattered through this literature, like glittering jewels in gray sand. But there is also much glass and cinder. Some points of warning are worth mentioning.

To begin with, many books on scientific communication boil down to collections of rules, standards, and warnings. Some even claim to offer the opposite, but end up embracing the enemy. Such books will tell you:

"Keep all your sentences short and simple" and "Avoid emotional terms." They may order you to "employ the active tense whenever possible" or to "follow the IMRAD structure (Introduction, Methods, Results, and Discussion) in all your papers." And so on. This type of advice, if viewed with the rigor of its own prescriptions, becomes a list of absolutes, like Martin Luther's *Ninety-Five Theses*, to be nailed to the door of every science department in the land.

From a certain point of view, the learning of rules makes sense. Science, after all, is awash in protocols, principles, and standards. Why not apply this to writing? Certainly it can be done. But let us be clear about what it means. The real focus is less on writing per se than on obeying codes of authorial behavior. One is not encouraged to be a true apprentice, to learn from the writing of other scientists, but instead to submit and conform to regulations. That is why these manuals so often adopt a tone of law enforcement ("You should never . . ."). But there is a deeper problem. Rule-driven advice can easily overwhelm us and validate any discomfort we already feel toward writing. Tiptoeing through a minefield of potential errors does little to advance confident steps toward the authorial act. Such advice thus tends to provide us more with the measure of our failures than aids to our success.

Let me give a specific example. Many manuals spend much space laying out precise standards for various items—references, tables, format, article structure, and so forth. Most or all of this is likely to be of little or no value. No universal standards exist for such elements. Different fields often handle them differently. This is just as true for journals, even within single fields. For such reasons, studying the literature of your discipline is the *only* guaranteed way to gain practical knowledge of these conventions.

This brings up another problem area. Authors of writing guides in science tend to offer counsel that reflects their own (inevitably limited) experience. What is good for biomedicine or agronomy, however, is not necessarily good (or even relevant) for chemistry or cosmology. The supposedly universal IMRAD structure is nothing of the kind. Appropriate to experimental work, it is rarely, if ever, followed in large portions of the geosciences, mathematics, physics, engineering, and many other domains where fieldwork, theory, and descriptive efforts are on exhibit. There has never been a single standard for scientific papers, and saying there should be is like claiming there is one and only one procedure for performing all experiments. Any attempt to call for universal standards smacks of authoritarianism, in a domain that has long proven adept at resisting all such im-

positions. Like nature, scientific work is highly diverse. Needed instead of despotic law is kind advice on *how to learn* what is accepted practice.

Such is all the more true since aspects of scientific publication are in flux in the early 21st century. The world of scholarly publishing as a whole has entered a period of dynamism but also uncertainty. Of course I am speaking about the online universe, which is where just about all scientific expression is headed, if it isn't there already. Rules and preferences, as well as required information, for online papers have evolved, with some journals now asking for inserted links to references, "additional" or "supplementary" materials, and more. The rise of open-access journals, in their various forms, continues to change the landscape of scientific publishing in major ways that all professional scientists need to understand. To that end, since the *how* of publication has large impacts on the *what*, this book will devote some important pages to these topics.

The Approach of This Guide

This is a book about professional scientific communication—what it is, how it can be achieved, understood, and improved. It is written by someone with long experience as an author and presenter both of scientific material and scholarly studies on scientific language. During my career as a geoscientist, I have authored an immodest number of technical papers, monographs, reports, and proprietary studies. At the same time, I have long been fascinated with the discourse of science and have written books and scholarly papers on the rhetoric of science, its historical evolution, its character in various languages, and the translation of it. What appears in this book, therefore, comes from both experience and knowledge.

The focus is on written expression. This is what every scientist must know how to do, bar none. There are also chapters on professional speaking, dealing with the press, communicating with the public, and other topics. Though mainly a book for scientists who write for other scientists, it extends its reach into other key areas where scientific work is communicated.

Fair weight is given to the journal article. Though admittedly a small subset of the total range in technical expression, the journal paper is the dominant—and most scientists and institutions believe the most important—form in which scientific knowledge continues to reside. The scientific journal began 350 years ago, became prevalent in the 19th century, and

evolved into an inarguable standard during the 20th century. It may change in the future; new forms of exchange may well emerge. But for now, and the foreseeable future, both online and hard copy science will continue their loyalty to journal-type publication.

So what kind of writing *is* scientific writing? There are two answers, both essential. First, scientific writing is storytelling. You will hear this from other writing guides, and they are right. Consider the subheads of a paper (any paper): it is apparent we are being told about something that happened—what it was, how it was made to occur, what resulted from it, and what it means. But there is a second dimension, too. Scientific writing is also engaged in rhetoric—it aims not just to tell but to persuade. It wants to convince us that the result not only has meaning but is *meaningful*. Such is no less important than the story; indeed, it needs to be the point of the story, as we will see.

In general terms, this is a book of advice, not rules; guidance, not demands. It is my experience, from years of publication and teaching, that scholars of any stripe learn best how to write well if they are addressed *as writers*, not as mere laborers, toiling in the mills and quarries of the word.

What does this mean? A certain shift in dignity, to begin with. But more to the point, it means providing you, the writer, with certain understanding, techniques, and attitudes that will aid you in gaining command over the language you produce and consume for a living. This I hope to do in three fundamental ways. First, I review some points on the nature and history of scientific discourse—this gives us context and a realistic sense of what we can expect of ourselves. Second, I maintain that good writing very often has a base in reading—I mean, reading as writers do, with a critical eye and an ear for quality, for what is worthy of imitation. This leads directly to the third and final point: good communicators learn from others, by identifying and studying examples of successful expression in their chosen field.

This last idea is probably the most important of all. It is a very old and deeply tested truth: authors acquire a comfort and facility for writing by first emulating the excellent work of others. This has always been true, and often admitted, for poets, novelists, playwrights, essayists, and scholars generally. Indeed, the use of models was a central aspect of Western education from at least the time of Quintilian (first century BCE) down to the late 19th century (why this changed is a complicated story). As a general method, it remains very much alive in the arts and humanities today. Expe-

rience teaches that scientists most often learn to write this way, too, though on a haphazard basis, since we don't tend to acknowledge it very much or make it an overt part of training.

The thoughtful use of positive and negative models, however, has another prominent advantage. It allows you, the writer, to chose your own teachers (or coaches, if you prefer). Writing is a personal activity, as I have said. But it also makes you part of a community of producers, such that you can improve your skills by drawing on the good work that other members have done. I will have more to say on this matter below. For now, let me leave you with a phrase by one of America's preeminent poets, T. S. Eliot, who once suggested that no artist is ever a complete original but must be set "for contrast and comparison, among the dead."

A word concerning what this book is *not* about. It is not about teaching you grammatical rules or proper scientific usage. There are other volumes along these lines; this book assumes that you are able to form a competent sentence in this language, at least some of the time, and that you know how to use a dictionary. If so, read on; this book is for you. It is also for those with English as a foreign language, to whom I have devoted a separate chapter. Those unable to write grammatically in any language need to begin somewhere else, however. They should have been either bored or scared off by what has been said to this point in any case.

Please think of using this book in several different ways. The next three chapters (2–4) form a unit, lay out the major themes, and will be most rewarding if read together (in order, if possible). Chapter 5 takes some of these themes to a higher level and may not be for everyone. Succeeding chapters, on the other hand, can be either perused in similar fashion, one after another, or dipped into, one at a time, as need or interest arises. If nothing else, I would like you to come away from this book with a changed view of scientific expression—what it is, what makes it up, where it is going, and, above all, how to use it. If even part of this is achieved, a good deed will have been done.

A Final Introductory Word: Philosophies of Language

I have said that the way in which one views language has an important effect on how one uses it. Scientists have been prey, for some time, to a particular philosophy of language that tends to derail their understanding of what might be termed "the scientific message." I refer, specifically, to the

overriding maxim "Simplify, simplify." There are many variations on this theme; no doubt you've heard some of them: "Use as few words as possible," "Eliminate anything that is not essential," "Scientific writing must be transparent, a mere vehicle," "Use the active voice at all times," and so forth.

All such ideas exhibit a deep misconception about the nature of technical discourse. The "simplify to the *n*th degree" mentality is a way of declaring martial law on the inevitable complexities of scientific communication. Besides embodying a philosophy of distrust, this way of thinking lacks any appreciation for the rhetorical *flexibility* of technical writing, as a form of human expression, and the range of literary techniques such writing normally includes—indeed, *must* include. To persuade and convince a highly critical audience, authors cannot simply brain-dump information onto paper. If they could, there would certainly be no need for a book of this type. We would all be masters, with no need of apprenticeship.

Let me give an example. One of the rules most common to the "simplify" philosophy is that the scientific writer should do away with any and all phrases such as "under these or similar circumstances," "it is important to note," "for the most part," "it is doubtful that," and so on. These kinds of fragments, however, though perhaps inessential as far as the data goes, perform a required function in good writing. They act as transitions between sentences or paragraphs and serve as helpful cues for the reader. They add pacing, flow, and important internal connection to the argument.

Effective arguments in any area of study, that is, employ a host of persuasive techniques. Many such techniques, in fact, are used equally by scientific and literary writing, though in different ways. This can be easily shown by a close analysis of any technical paper (see chapter 2). At a fundamental level, there is no deep divide between the sciences and the humanities when it comes to the basics of expression. Only, perhaps, a series of guarded trenches.

A main goal of this book is to help make scientific writers and speakers aware of the forms that they are using, or might use, when they produce competent science. This means learning to read with a critical eye and understanding how specialized the scientific message really is. Writing, in particular, is a messy business. It is as full of trial and error, dead ends, frustrated effort, and minor triumphs as any other part of research. What eventually emerges (hopefully) is a reasonably well-organized, logical flow that hides most (but never all) of this struggle. In the words of Peter Medawar, Nobel laureate in medicine and frequent author on matters of science, "the scientific paper is a fraud." But then, so is all successful writing.

Scientific communication is highly stylized—far more stylized, in fact, than forms such as the literary essay. When we look back at the past, say to the 17th century, and trace technical expression forward, we find that what we are doing when we write is telling very condensed, extremely formalized "stories" to an equally particular audience. In most cases, we have learned to do this through imitation, another trial-and-error process. Consciously or otherwise (usually otherwise), we are employing strategies to convince the reader of our knowledge, competence, originality, and contribution. This seems a tall order, when put this way. It is both ordinary and magnificent. Perhaps the sense that all of this is going on helps make us the critical, scrutinizing, and often skeptical beings that we are. But it should also reconnect us with the reasons why we originally chose to do science, the wonder and fascination, the ambitions and desires, that propelled us in this direction. Writing is about these aspects of our lives, too. Scientists are also writers because science is a great presence in the world.

2. THE LANGUAGE OF SCIENCE: HISTORICAL REALITIES FOR READERS AND WRITERS

All that a scientist creates in a fact is the language in which he enunciates it. —HENRI POINCARÉ

Matters of History

As scientists, we are largely creatures of the contemporary. Unlike other areas of study, our training provides little on the history of our discipline or the development of our discourse. Does scientific language even *have* a real history? What would Newton or Laplace make of a recent article in *Physical Review Letters*? If Darwin's *Origin of Species* were submitted to a major scientific publisher today, what might be its chances of acceptance (or should we say, survival)?

These are not merely academic questions. Scientists communicate with each other in a professional dialect, one that has evolved. Language stands still for no one, and scientific language is no exception. If you doubt this, I urge you to read through articles in your own field written 50, 75, and 100 years ago: the differences from today will be both obvious and subtle. In fact, let me offer a few examples here.

> Anno: 1672. In the year 1666 . . . I procured me a triangular glass prism, to try therewith the celebrated phaenomena of colours. . . . It was at first a very pleasing divertissement, to view the vivid and intense colours produced thereby; but after a while . . . I became surprised to see them in