Chapter 1

# Introduction: Deciding Where to Begin

*But in science the credit goes to the man who convinces the world, not to the man to whom the idea first occurs.*

—Sir Francis Darwin

Many people underestimate how difficult scientific writing is. One aspect that makes scientific writing difficult is the inherent complexity of the subject matter. Some subjects such as eddies in a turbulent flow are complex because they are so random. Other subjects such as the double helix structure of DNA are complex because they are so intricate. Still other subjects such as the quantum orbits of electrons are complex because they are so abstract.

Besides the inherent complexity of the subject matter, a second aspect that makes scientific writing difficult is the inherent complexity of the language. Scientific language is full of specific terms, unfamiliar abbreviations, and odd hyphenations that you don't find in other kinds of writing:

> This paper shows how intensity fluctuations in the frequency-doubled output of a Nd:YAG pump laser affect the signal generation from coherent anti-Stokes Raman spectroscopy (CARS).

"Frequency-doubled," "Nd:YAG," "CARS"—these aren't the kinds of expressions that you run across in the morning paper. They are a part of a different language, the language of lasers. In science and engineering, there are many such languages, and these languages are rapidly evolving. Adding still more complexity to scientific writing are mathematical symbols and equations:

> The burning rate ($\Omega$) of a homogeneous solid propellant is given by the following equation [Margolis and Armstrong, 1985]:

$$\Omega = \frac{\rho}{\alpha}(2\lambda\tau)^{1/2} Le^{n/2}\left[\frac{c(1-\sigma)}{(c-\sigma)(1+\gamma_x)}\right]$$

In addressing these complexities of scientific writing, this book does not offer simplistic advice. Nor does it consider only watered-down problems. Rather, this book presents scores of real-world examples that reveal the differences between strong scientific writing and weak scientific writing. In essence, what this book does is make you a critical reader of scientific writing so that you can revise your own work.

## Establishing Your Constraints

Whenever I teach writing to scientists and engineers, I begin by asking how they would solve a technical problem, such as the flight of a launched projectile. Here, each scientist and engineer begins the same way, by defining the problem's constraints. What is the projectile's initial velocity? What is the projectile's shape and roughness? What is the projectile's drag? Then I ask how to begin writing a document about the same technical problem. At this point the answers vary. Some people want to write an outline first. Others want to draft an introduction. Still others want to assemble the illustrations in a storybook



fashion. This variation in where to begin writing a document is one reason that so many scientists and engineers struggle with their writing.

So, where should you begin writing a scientific document? Actually, you should begin writing a scientific document at the same place that you begin solving a scientific problem: establishing the constraints. More times than I can count, I've run across instances in which a scientist or engineer at the request of a manager has spent days or weeks writing a report, only to have the first draft come back bleeding in red ink because the author assumed one set of constraints for the document and the manager assumed another. Just as you wouldn't pull out equations to solve a technical problem until you understand the problem's constraints, so too should you not start writing sentences and paragraphs until you understand the document's constraints. In scientific writing, there are four principal constraints to consider: the audience for the document, the *format** for the document, the *mechanics* of the document, and the politics surrounding the document.

In addition to the four imposed constraints, there are two variables that you, the writer, bring to the situation. The first is the work that you want to present. Each area of science and engineering has its own set of terms, symbols, and abbreviations that readers expect you to use. The second variable is the purpose that you have for the document. In scientific writing, you write for two specific goals: to inform readers and to persuade readers. In many documents, you do both. For instance, in a proposal to purchase a certain model of streak camera, you would inform readers about how a streak camera works. In the same proposal, you would persuade readers that one model camera should be chosen over other models.

***Audience.*** The audience of your document determines which words you define, what kinds of illustrations you

*All terms in italics are defined in the Glossary.

use, and how much depth you achieve. Success in scientific writing depends on you making a bridge to your audience. You wouldn't write the same document on gene therapy to a Congressional committee that you would to an international conference of researchers. If you did, you would either overwhelm the Congressional committee or not satisfy the international conference. Because each word and image depends on your audience, defining your audience is the place to start writing the document.

In scientific writing, unlike journalism, the types of audiences vary tremendously. While a newspaper reporter writes each story to essentially the same general audience, a scientist or engineer writes to many different audiences. For example, let's suppose that you used technology from weapons research to design an electronic implant for delivering insulin to diabetics [Carlson, 1982]. You might write one document to other engineers who are familiar with the electronics of your design, but not with its application to combatting diabetes. You might then write a second document to medical doctors familiar with diabetes, but not with the electronics of your design. In yet a third document, your audience might be managers who hold the purse strings for your project, but who are unfamiliar with both diabetes and electronics. Here you have three different audiences and three different documents.

The key word in tailoring your writing to the audience is "efficiency." When the purpose of the writing is to inform, efficiency refers to a style that communicates the most amount of information in the least amount of reading time. Put yourself in the shoes of the audience. Many times, when you read a document, you're interested in only the most important details. Too often, though, scientists and engineers present their work as if they were explaining a murder mystery—saving what they think is best for last. The problem is that many readers never get



far enough in the document to see the most important details, and many of those who do get far enough are not able to distinguish the most important details from the avalanche of other details. Efficient writing, though, emphasizes important details by placing those details where they stand out.

When the purpose of the writing is to persuade, efficiency refers to a style that presents logical arguments in the most convincing manner. These two styles (the informative and persuasive) differ at times. For instance, while you state your conclusions up front in purely informative documents, you sometimes withhold your conclusions in persuasive documents, especially when the audience includes readers who are antagonistic to those conclusions. An example situation would be a report to the public that recommends a site for a nuclear waste repository. In such a report, you would be better off beginning at a point that no one disputes (perhaps the importance of safety for the surrounding area) and methodically working from that point through your methods until you arrive at your conclusions. In this situation, by keeping the audience in the dark about your conclusions, you create the opportunity to gain credibility with the audience and to present your case before your opposition tunes you out. Will such a strategy convince everyone to accept your conclusions? No. However, if your arguments are cogent, some readers who were on the fence or mildly against the conclusions might swing over, and some who were vehemently opposed might lose some of their vehemence.

No matter what document you are writing, you should assess the audience: (1) who will read the document, (2) what do they know about the subject, (3) why will they read the document, and (4) how will they read the document. These questions dictate how you write the document. In answering the first question, you assess what types of readers you have. Sometimes you have only one type of reader—managers, for example. In more difficult situations, you have a mixture of audiences: managers, scientists and engineers in your field, and scientists and engineers from other fields.

In answering the second question, you assess how much your audience knows about the document's subject matter. From that answer, you can decide what background information to include and which terms to define. Note that when you have a mixture of audiences, you should assess which readers constitute your primary audience and which readers make up your secondary audiences. That determination is important for the organization of the document. In a formal report, for example, the primary audience you address in the *main text*, and the secondary audiences you address in the *back matter*.

In answering the third question, you discern what information the audience is seeking in the document. From that answer, you can decide which results to emphasize. In scientific writing, it is not sufficient that you just logically organize the details. You also should give appropriate emphasis to the details.

Finally, in answering the fourth question, you assess the manner in which the audiences will read the document. Will they read it from beginning to end or will they read only certain sections? Will they just scan the document or will they methodically read through it? Letters, for example, are read quickly, and for that reason, strong writers keep sentences and paragraphs in a letter relatively short. That style allows the audience to sprint through the letter and yet digest the information.

**Format.** A second constraint of scientific writing is the document's format. Format is the way the type is arranged on the page. Format includes such things as the typeface used, the way the pages are numbered, the way sources are referenced, and the length of the document.



There is no absolute ordained format for scientific writing. Because most journals, laboratories, and corporations establish their own formats, these formats vary considerably (for some general guidelines regarding format, see Chapter 16). What's important is that you follow the format of your situation. If the format for a patent application asks for a line drawing, you supply one. If the format for a company report asks for an executive summary, you supply one. If the format for a proposal asks for a statement of the problem, you supply one.

Many scientists and engineers fret over the different formats in scientific writing. Why, for example, does *Journal A* use one type of referencing system, while *Journal B* uses another? These scientists and engineers seek absolutes in scientific writing; they mistakenly treat scientific writing as a science instead of a craft. Instead of worrying about format, over which you may have little control, you should worry about *style*, something you do control. For example, you should worry about your word choices, the complexity of your illustrations, and the way you structure your papers. Stylistic decisions determine whether readers understand your work. Stylistic decisions determine the success of your writing.

**Mechanics.** A third constraint of scientific writing is mechanics. Mechanics encompasses the rules of grammar and punctuation. Because science and engineering are based on logic, many scientists and engineers find mechanics frustrating for several reasons. First, there are many rules. For instance, it's not unusual for a mechanics handbook to devote twenty or more pages to rules governing the comma. Second, the rules of mechanics in English have many inconsistencies. One example is where end quotation marks are placed. In the United States, end quotation marks appear outside of periods and commas. In Great Britain, however, end quotation marks often appear inside periods and commas.

A third reason that many scientists and engineers find mechanics difficult is because of the large amount of gray area. For instance, do you refer to the years between 1990 and 1999 as the 1990s or the 1990's? Actually, this aspect of mechanics is governed by format. In *Scientific American*, for instance, it is proper to write 1990s. In *The New York Times*, 1990's is proper. Finally, many scientists and engineers find mechanics frustrating because the English language is constantly changing. A rule that applied in the 1920s (the expression of Roentgen rays as "X rays") does not apply today (at present, "x-rays" is proper).

No simple advice exists to handle the maze of mechanics rules in the English language. As a writer, you have to distinguish between the hard rules, such as the spelling of the word "receive," and the semi-hard rules, such as forming the possessive of a singular noun by simply adding *'s* (an exception would be "Mount St. Helens' eruption"). For more discussion about mechanics, see Appendix A and Appendix B.

***Politics.*** The fourth writing constraint, the politics surrounding the document, is the most difficult to discuss. In an ideal world, this constraint would reduce to the simple statement that you remain honest. Staying honest is straightforward enough. For instance, if you know that your vacuum pumps have coated your experiment with mercury vapor and you suspect that the vapor has altered the results, then you would be dishonest if you did not state your suspicion.

Unfortunately, the world is not ideal, and scientists and engineers are often constrained in their writing not only by the need to remain honest, but also by the need to satisfy lawyers and bureaucrats. Illustrating this point is the poor communication between engineers and management preceding the space shuttle *Challenger* accident. Well before the accident, engineers at Morton Thiokol



International, a contractor for the shuttle, not only knew about the O-ring erosion in the shuttle's field joints, but also had evidence that lower temperatures would exacerbate this problem [*Report*, 1986]. When temperatures plunged below freezing the night before the fateful launch, the engineers tried to have the launch stopped. However, they were rebuffed by their own management at Thiokol and by NASA officials at Marshall Space Center. Why? One reason was the political atmosphere surrounding the shuttle launches at that time. NASA was under such political pressure to launch the space shuttle, and to launch it often, that agency officials and contractors were hesitant to raise issues that would slow the schedule.

Political pressures frustrate scientists and engineers in their writing. I wish that I could say something that would make these constraints go away, but I can't. In some dramatic cases, such as the space shuttle *Challenger*, the political constraints force you to face your ethical responsibilities as a scientist or engineer and to act accordingly. In most cases, the stakes aren't nearly so high. In these smaller cases, the important thing is that you distinguish between the political constraints imposed on that document and the stylistic goals desired for all the rest of your writing. Just because a company lawyer insists that you be wordy in one paragraph does not mean that wordiness is a desired goal for scientific writing.

## Selecting Your Stylistic Tools

If you asked ten scientists and engineers to define the term "heat convection," you would receive essentially the same answer ten times because most scientific and technical terms are universally defined. However, if you were to ask the same ten scientists and engineers to define the writing term "style," you might receive ten different answers. Unfortunately, no universal definitions exist for scientific writing—which is one reason that so much confusion exists about the subject.

In this book, style is the part of writing that you, the writer, control. Style is the way in which you cast your thoughts into words and images. Style includes such things as the way you emphasize details, the sentence lengths you choose, the level of detail you use in your line drawings. Style comprises three elements: structure, language, and illustration.

***Structure.*** Structure is the strategy of a scientific document. When most people think about the structure of a document, they think of the word "organization." Granted, the organization of details within the document is a major part of structure, but structure also includes the depth of details, the transitions between details, and the emphasis of details. Structure is the most important element of your style. When your language or illustration falters, your trail breaks and you trip your readers. However, when your structure falters, your trail ends and you lose your readers.

How do you choose the best structure for a document? Given the wide range of topics and audiences in science and engineering, this question is difficult to answer. Despite that difficulty, many scientists and engineers search for template outlines to handle their writing situations. These authors collect template outlines for formal reports, informal reports, feasibility reports, completion reports, and so on. This approach is flawed. For one thing, who wants to keep track of all those outlines? For another thing, when applied to real writing situations, these template outlines just don't work. Granted, you can point out common structural threads for such documents as correspondence, proposals, and instructions, but to lump all proposals into a single packaged outline doesn't



make sense. How can one packaged organization work for both a ten-million-dollar grant to contain nuclear fusion with magnetic mirrors as well as a fifty-thousand-dollar grant to study the effects of insects on artichokes. If the outline does work for both projects, then it's so general that it's not worth memorizing, and if the organization does not work, as is probably the case, then you've sacrificed grant money for the convenience of a paint-by-numbers strategy.

Rather than present paint-by-numbers strategies, this book shows the differences between documents with strong structure and documents with weak structure. In doing so, this book examines structure from four perspectives: the organization of details, the transition between details, the depth of details, and the emphasis of details. For each perspective, strong and weak examples are shown.

***Language.*** Language is the way that words are used. Language is not only the choice of words, but also the arrangement of those words in phrases and sentences. In scientific writing, language includes the use of numbers, equations, and abbreviations; it includes the use of examples and analogies.

In scientific writing, your language must first be precise. You must say what you mean. Your language must also be clear. While precision means saying what you mean, clarity means avoiding things that you don't mean. Besides being precise and clear, you should be forthright in your language. When you write a scientific document, you assume the role of a teacher, and as a teacher you want to convey a sincere and straightforward attitude. Another goal of language is to anchor your language in the familiar. In other words, you should use language familiar to your readers. Before readers can learn anything new, they have to see it in relation to something they already know.

Moreover, because scientists and engineers produce so much writing, they have an obligation to keep their language concise. Every word should count. Although you should make your language concise, you should also make it fluid. Fluid writing is smooth writing, writing with transition, writing that moves from sentence to sentence, paragraph to paragraph without tripping or tiring the reader.

These six goals for language do not all carry the same weight. Precision and clarity are the most important. The relative importance of the other goals depends on your audience and work. For instance, in an abstract paper about quantum mechanics, being familiar might become more important than being concise. In this paper, you could add analogies to help readers understand your ideas.

Don't assume that these six goals for language are in constant conflict. Most of the time, these goals reinforce one another, as shown in Figure 1-1. When you are clear and forthright, conciseness follows. When you are precise and familiar, clarity follows. Also, don't think that by pursuing these six goals you will lose your individuality as a writer. Within these six goals there is much variation. Pursuing these language goals will not cause your writing to sound like everyone else's; rather it will make your writing succeed.

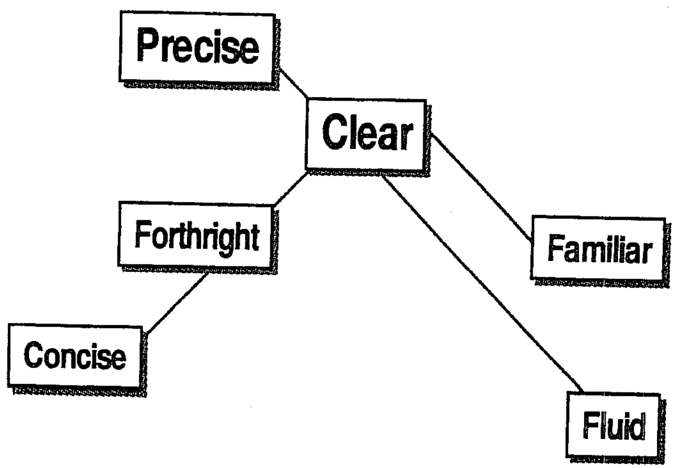


**Figure 1-1.** Six goals of language in scientific writing. Precision and clarity are the most important.



***Illustration.*** Illustration is not just the presence of figures and tables in a document. Illustration is the meshing of figures and tables with the language. Just pasting pictures into your paper is not strong scientific writing. In fact, a slapped-in figure or table may confuse your readers more than inform them.

Other types of writing, such as literary novels, do not generally use illustrations. Why do we use illustrations in scientific writing? Unlike the purpose of fiction, which is difficult to define, the purpose of scientific writing is straightforward: either to inform or to persuade the audience as efficiently as possible. Illustrations can help make your writing efficient by clarifying images that are too complex to be conveyed by language. For instance, just telling your audience that the eruption of Mount St. Helens in 1980 had an ash plume that reached 19,000 meters and dispersed 0.67 cubic kilometers of material into the atmosphere is not nearly as effective as anchoring that data with an illustration such as Figure 1-2. Note that just having the figure without the accompanying data would not have been effective because the readers would not have known the heights and amounts involved.

Besides making the reading more efficient, illustrations can also make the writing more efficient. Imagine presenting the information in Table 1-1 in sentence form. Without the table, you would end up writing strings of tedious sentences that would simply list measurements and ratios. Also, without the table, your readers would waste much time sifting through these sentences to find specific details such as the gravity on Jupiter.

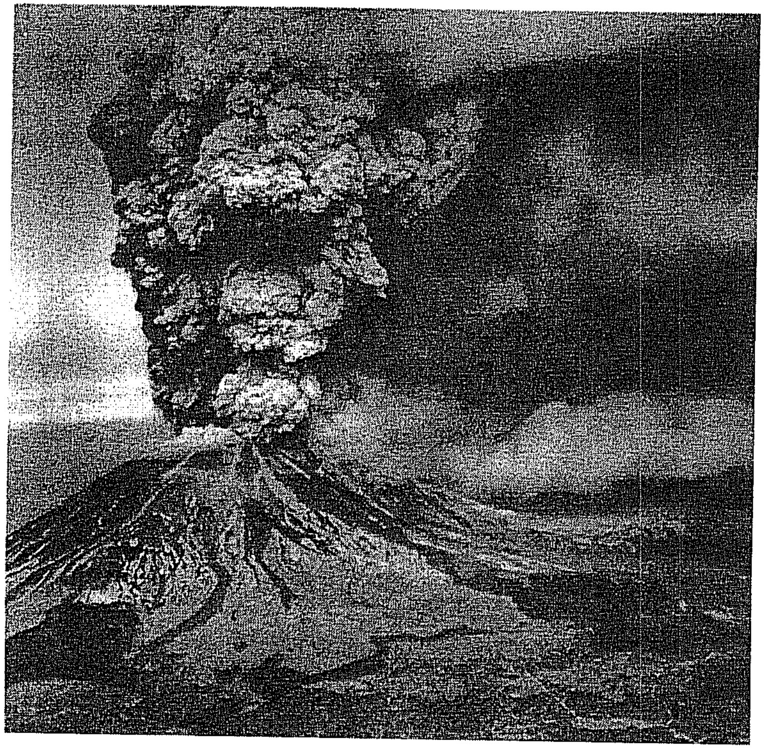

**Figure 1-2.** Eruption of Mount St. Helens in 1980 (courtesy of the United States Geological Survey).

**Table 1-1**
**Characteristics of Planets**
**in Our Solar System [*CRC Handbook*, 1995]**

| Planet | Radius (kilometers) | Gravity ($m/s^2$) | Year (earth days) |
|---|---|---|---|
| Mercury | 2,440 | 3.70 | 88 |
| Venus | 6,052 | 8.87 | 225 |
| Earth | 6,378 | 9.80 | 365 |
| Mars | 3,397 | 3.71 | 687 |
| Jupiter | 71,492 | 23.12 | 4,333 |
| Saturn | 60,268 | 8.96 | 10,759 |
| Uranus | 25,559 | 7.77 | 30,685 |
| Neptune | 24,764 | 11.00 | 60,181 |
| Pluto | 1,151 | 0.72 | 90,470 |



Although illustrations can make your writing more efficient, you shouldn't fill your journal articles and formal reports with graphics in the same way that a comic book is filled with pictures. Too many illustrations will reduce the emphasis given to any one illustration and undercut the efficiency of informing. As with language, the way you illustrate depends on your constraints.

## References

Carlson, Gary, "Implantable Insulin Delivery System," *Sandia Technology*, vol. 6, no. 2 (June 1992), pp. 12–21.

*CRC Handbook of Chemistry and Physics*, 75th ed. (New York: Chemical Rubber Publishing Co., 1995), chap. 14, p. 3.

Darwin, Sir Francis, "Sir Galton Lecture Before the Eugenics Society," *Eugenics Review*, vol. 6, no. 1 (1914).

Hemingway, Ernest, interview, *New York Journal-American* (11 July 1961).

*Report of the Presidential Commission on the Space Shuttle Challenger Accident*, vol. 1 (Washington, DC: White House Press, 1986), pp. 104–110, 249.