# The Craft of Scientific Writing

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*For Karen*

# Preface

*Most people do not realize that writing is a craft. You have to take your apprenticeship in it like anything else.*

—Katherine Anne Porter

As an engineer or scientist, your writing affects not only how much credit you receive for your work but also how much influence your work has. In effect, the quality of your writing influences decisions by others on whether to hire you, to fund your ideas, or to publish your findings.

No doubt, in your schooling, you have taken courses on writing. As an engineer or scientist, you certainly will draw on those courses because they provide you the foundation of your craft. However, scientific writing poses challenges that general writing courses do not cover. First, the subject matter of scientific writing is significantly more complex. From the design of an artificial limb to the distillation of crude oil, the content of science is more specific, unfamiliar, and mathematical. Second, the type of audience varies much more in scientific writing than it does in general writing. In one scientific document, you might target experts in a field. In another, you might address politicians who have never taken basic chemistry or physics. Still a third challenge of scientific writing is that you as an author have to confront stylistic choices that you did not see in general writing courses: how to divide documents into sections, how to distill a large project into a concise summary, or how to integrate illustrations and equations with text.

The goals of this book are not only to help you meet those challenges but also to raise your scientific writing to the highest level. To do so, this book provides insights that are specific to scientific writing:

> Analyze not only what your audience knows, but also why they are reading.
> Keep things as simple as possible, yet no simpler.
> Begin with what is familiar before moving to what is new.

To anchor such insights, this book provides scores of examples from engineers and scientists around the world. In essence, these examples show you the differences between strong scientific writing and weak scientific writing. What distinguishes this book from the host of technical writing books on the market is that this book dives below the surface question of how engineers and scientists typically write scientific documents to the deeper question of how you should write your scientific documents. In other words, rather than spending hundreds of pages to show you the many stylistic ways that scientific documents are written, this book focuses only on the most effective strategies.

At this point, a fair question is what qualifies me to pass judgment on what is strong scientific writing and what is not. First, I was educated both as an engineer (master of science in electrical engineering) and as a writer (master of fine arts in fiction writing). Second, in the past 30 years, I have written and edited many engineering and scientific documents. Third, I have taught writing to thousands of engineers and scientists at respected institutions on four different continents and in seventeen different countries. Examples include AREVA Nuclear Power, the Army Corps of Engineers, Battelle Memorial Institute, the European Space Organization, Lawrence Livermore National Lab, Pennsylvania State University, Qatargas, Sandia National Laboratories, Shanghai Jiao Tong University, Simula Research Laboratory, the University of Sao Paolo, and Virginia Tech. The insights, questions, and challenges of engineers and scientists at those institutions have shaped, molded, and refined the advice in this book. In effect, those engineers and scientists have served as this book's editors.

Although this book focuses on effective styles in scientific writing, you should not assume that this book teaches you to write in a paint-by-numbers scheme. In science and engineering, the wide variety of audiences, purposes, and occasions precludes such an approach. Rather, this book makes you a critical reader of scientific writing so that you can craft a style for your situation. In addition, because you have only so many hours a week to devote to writing, this book dissects the ways that professional writers put words and images onto paper. In doing so, the book provides practical advice to make you more efficient at all four stages of the writing process: preparing, drafting, revising, and finishing.

I wish that this book would make your scientific writing easy. Unfortunately, scientific writing is hard work. The best scientific writers struggle with every paragraph, every sentence, and every phrase. They write, then rewrite, and then rewrite again. Scientific writing is a craft, a craft you continually hone.

University Park, USA Michael Alley
February 2018

# Acknowledgments

More than 40 years ago, my sixth-grade English teacher, Mrs. Hutton, drilled into my classmates and me an understanding for the parts of speech and how those parts combine into proper sentences. At the time, I did not appreciate Mrs. Hutton's efforts. Instead, I did the homework that she assigned and answered the questions that she posed in class, all the while fearing her reprimands and relishing her praises. To this day, I draw on her lessons every time I sit down to write.

Writing is not mastered in a single course. Looking back on my career, I am indebted to other teachers who insisted that my writing be clear, connected, and correct: Mrs. Anderson (9th grade English, St. Genevieve's of the Pines), Mr. James B. Fischer (Latin, The Asheville School), and Margaret Morgan (freshman composition, Texas Tech University). All of these teachers deepened my foundation for putting together clear and precise sentences and for connecting those sentences into coherent paragraphs.

Sadly, about 30 years ago, a misguided education movement in the United States seduced many writing instructors into no longer formally teaching the grammatical foundation of the English language. Instead, the movement, which aimed to make writing fun, relied on less taxing assignments such as first-person stories and *I believe* essays. An unfortunate result is that many young engineers and scientists today, as gifted as they are, do not have a firm grasp of what a sentence is, what it is not, and what it can be. In scientific writing, such a foundation is essential for crafting sentences and paragraphs that inform and persuade. Although this book does not cover everything that my writing teachers taught, this book distills their lessons into what applies most in scientific writing.

In addition to writing teachers who taught me the core principles of writing, I owe much to the many scientists and engineers who have shared their insights on scientific writing and editing. Foremost, I would like to thank my amazing wife, Prof. Karen Thole. Her successes not only as head of one of the largest engineering departments in the country but also as a leading researcher in gas turbine engines and mentor to more than 70 graduate students have provided many of the strong examples in this text. In addition, her energy, vision, and pursuit of excellence in her work have inspired me to aim higher in my own.

Much is also owed to the late Harry Robertshaw. For 7 years, the two of us interwove principles of measurements and writing into a laboratory course taken by hundreds of mechanical engineers at Virginia Tech. What that experience taught me is that even in large courses, you can continue the writing education of each student. The effective teaching of writing boils down to four steps: (1) providing insights to students on how to communicate the course's content, (2) having the students apply those insights in a meaningful document, (3) supplying feedback on that document, and (4) having the students use that feedback to revise.

Over the past 15 years, many of my best insights into scientific writing have arisen from working with Are Magnus Bruaset and the late Hans Petter Langtangen, both with Simula Research Laboratory. In particular, these two have strongly shaped this book's ideas about writing proposals. In addition, I would like to thank the following writing teachers who have influenced and inspired me on particular passages of the book: Christine Haas, Jean-luc Doumont, Christy Moore, D'Arcy Randall, Hillary Hart, Lesley Crowley, Warren Goldstein, and Brad Henderson. Moreover, deep thanks go to my parents—both chemists who instilled in me a love of science, nature, and reading.

My greatest debt, though, I owe to the students in my university courses and professional workshops. In particular, I would like to thank those from Penn State, Virginia Tech, the University of Oslo, Shanghai Jiao Tong University, the University of Wisconsin–Madison, the University of Texas at Austin, Simula Research Laboratory, AREVA Nuclear Power, Lawrence Livermore National Laboratory, and Sandia National Labs. You have challenged my advice, revised it, and made it more precise.

# Contents

# Introduction

*The greatest merit of style is to have the words disappear into thought.*

—Nathaniel Hawthorne[1]

When you as an engineer or scientist sit down to write, you make hundreds of decisions. Some are large, such as which details to emphasize. Other decisions are much smaller, such as whether to insert a comma after an introductory phrase. Although smaller, many such decisions occur so often that they deserve attention. No matter whether large or small, all decisions about writing fall under one of three categories: content, style, or form.

Content is *what* you wish to convey. In scientific writing, content varies widely—from experiments on atomic particles to theories about solar galaxies. Although essential for the success of scientific writing, content is not the focus of this book. Rather, an assumption in this book is that you have valuable content to convey.

Style, on the other hand, is *how* you convey the content to the audience. For example, style includes the ways in which you cast your ideas into sentences and how you connect those sentences into paragraphs. Style also concerns how you combine those paragraphs with illustrations to create sections and how you arrange those sections into documents. The first nine lessons of this book focus on achieving an effective style in scientific writing.

[1] Adapted from Nathaniel Hawthorne (1951), letter to an editor, https://www.thoughtco.com/plain-style-prose-1691632.

Form then consists of the writing rules that readers expect you to follow, such as how to use a colon properly, when to write out a number, or the guidelines for inserting a reference listing into the text. Many such rules are universal. For instance, with only a few exceptions, the rules for ***grammar***,[2] punctuation, and ***usage*** are the same in Seattle as they are in Sienna or Shanghai. Appendices A, B, and C focus on the rules of grammar, punctuation, and usage that cause the most problems for engineers and scientists. Other rules are local—such as guidelines for ***format***, which comprises the typography and layout of a document. In most cases, the format that you select for a document depends on the publication or institution. However, for those situations in which you have to design the format, Appendix D presents guiding principles for achieving a professional look.

While the perspectives of content, style, and form help you decide which words and images to select, another important perspective is you, the writer. More specifically, what is your process for placing those words and images onto the page? As an engineer or scientist, because you have only so many hours each week to devote to writing, the time that you spend writing should be efficient. Drawing on the advice of professional writers, Lesson 10 in this book analyzes the four stages of sitting down to write a document: preparing, drafting, revising, and finishing.

[2] Terms in boldface italics are defined in the Glossary.

# Analyzing the Audience, Purpose, and Occasion

*The major weakness that I see in papers by young researchers is that they organize their writing to parallel the time and effort required for the various aspects of the research. So, if they spent 90 percent of their time doing X, they seem to almost inevitably organize the paper so that 90 percent of the paper is focused on X—even when the most interesting and significant results are in the other 10 percent* [1].

—Andrew Zydney

On the morning of January 28, 1996, the Space Shuttle Challenger took off from Cape Canaveral, Florida. On board were seven astronauts, including the first civilian in space: the middle school teacher Christa McAuliffe. Because this launch included the first teacher in space, many school children across the country watched on television. Tragically, the shuttle exploded 73 seconds after takeoff, killing all seven astronauts on board. About 60 seconds into the launch, as captured on film, a flame emerged from the middle portion of the right solid rocket booster. Over the next 3 seconds, the flame expanded into an explosion. Because of this photographic evidence, the investigating board quickly focused on the solid rocket boosters as the source for the explosion. One of the board's


M. Alley, *The Craft of Scientific Writing*,
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# Balancing Precision with Clarity

*In scientific writing, keep things as simple as possible, yet no simpler* [1].

—Albert Einstein

Einstein's advice to keep the language as simple as possible, yet no simpler, calls for a balance between being precise and being clear. Foremost, your scientific writing has to be precise. Otherwise, you are not communicating the work. While being precise requires you to convey what you mean, clarity calls on you to avoid things that you do not mean. Achieving this balance begins with choosing the right word. As Mark Twain said, "The difference between the right word and the almost right word is the difference between 'lightning' and 'lightning-bug'" [2]. In addition, achieving this balance of precision and clarity requires you to find the appropriate level of detail for the audience and then, as Einstein said, avoid any complexity above that level. Moreover, this balance should apply not only to your language but also to your illustrations.

## Choose the right word

As an engineer or scientist, you would not choose the word *weight* when you mean *mass*. Technical terms such as *weight* and *mass* have specific meanings. Many ordinary words have specific meanings as well. For instance, the author of the following sentence chose a word with an incorrect meaning:


M. Alley, *The Craft of Scientific Writing*,
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> Our team came up with a plethora of designs.

The word *plethora* is misused here. This word does not mean "many," as many mistakenly assume. Rather, the word *plethora* means "too many." What the author wanted to convey was

> Our team came up with a host of designs.

In scientific writing, you should not select a word unless you are sure of its meaning. If you have the slightest doubt, look up the word in the dictionary. In this example, the engineer chose *plethora,* which is a fancy word, to impress the audience. Unfortunately, for those readers who know the word's meaning, all the word choice did was to undercut the engineer's credibility.

Consider another word that is commonly misused:

> For two weeks, we continuously sampled the levels of chlorine in the stream.

Because *continuously* means without interruption, as in "a continuous spectrum of light," and because the scientists did not forego sleep for two weeks to make the measurements without interruption, the sentence is imprecise. The word that the scientist wanted was *continually*, which means on a regular basis:

> For two weeks, we continually sampled the levels of chlorine in the stream.

As discussed in Appendix C, a number of word pairs, including *affect* versus *effect* and *principal* versus *principle*, cause similar problems in scientific writing.

In addition to avoiding words with an incorrect meaning, another aspect of being precise is to avoid word groupings that make no sense:

> The problem centers around the drying and aging of the bloodstain.

Geometrically speaking, the phrase *centers around* makes no sense. What the writer wanted was either *centers on* or *revolves around*. Appendix C discusses other nonsensical expressions including *comprised of* and *very unique* that many engineers and scientists mistakenly select.

A number of problems with word choice do not arise from confusion with other words or from groupings that create nonsensical meanings. Rather, these problems arise because only one word suffices and any substitute causes imprecision. Despite what your grade school teacher might have taught you, few words, if any, are exact synonyms. Some words have similar meanings but are not interchangeable. Consider, for example, these two terms from the electrical breakdown of gases:

**gas discharge:** any one of the three steady states of the electrical breakdown process. The three steady states are the Townsend, glow, and arc.

**spark:** the transient irreversible event from one steady state of the electrical breakdown process to another (example: the transition from a glow discharge to an arc)

To use these two terms as synonyms is imprecise language. The first term is a steady state, and the second term is a transient. However, in the first sentence of a review article in a respected journal, the author tossed these terms around as if they were in the same class:

> The last decade has seen a rapid development of new techniques for studying the enormously complex phenomena associated with the development of sparks and other gas discharges.

Because a spark is not a type of gas discharge, this sentence is imprecise. More important, because this sentence is the first sentence of the article, this imprecision undercuts the article's authority. Why did the physicist make this mistake? Given that the article was an invited review article, the physicist certainly understood the meanings of these two words. Most likely, the mistake occurred because the physicist focused on the rhythm of the sentence rather than on the meaning. In other words, the physicist wrote the sentence as if being fluid was more important than being precise—a stylistic choice sometimes appropriate for poetry but not for scientific writing.

Some writing teachers spread the misconception that using synonyms is a mark of a good writer. These teachers advocate relying on a thesaurus when you write. Well, synonym writing is not strong writing. Even when you find true synonyms, using them often confuses your readers:

> Mixed convection is a combination of natural and forced convection. Two dimensionless numbers in the correlations for mixed convection are the Grashoff number and the Reynolds number. The Grashoff number (for free convection) is a measure of the ratio of buoyant to viscous forces, and the Reynolds number (for forced convection) is a measure of the ratio of inertial to viscous forces.

Why did the engineer use "free convection" instead of "natural convection" in the third sentence? This synonym substitution added nothing to the discussion and served only to confuse readers unfamiliar with the vocabulary of heat transfer.

Another reason not to use synonyms is how inexact synonyms are. Consider how quickly this string of synonyms, taken from a thesaurus [3], arrives at the antonym of the first word:

> classified → secret → mysterious → unidentified → unclassified

Most professional writers, including fiction writers, do not hesitate to repeat a word if that word is the right word. To find the right word, you will want to use a dictionary, not a thesaurus. While a thesaurus identifies possible right words, a good dictionary reveals the subtle differences between those possibilities.

Besides the dictionary meaning (or ***denotation***) of a word, you should also think about the word's associated meaning (or ***connotation***). Many words, such as *cheap*, conjure an associated meaning that works against the dictionary meaning. In the dictionary, *cheap* means inexpensive. However, the connotation of *cheap* is shoddy in construction. For that reason, you would not describe your proposed solution as "cheap."

For people not writing in their native language, recognizing the connotations of words is challenging. While living in Germany for 2 years, I built up my German vocabulary by reading mysteries (*Krimis*) at night. Then, during my daily visits to the bakery, market, and bookstore, I would try out my new words. Usually, the new words were readily accepted but on occasion, the horrified look behind the counter revealed that one of my new words had an inappropriate connotation. While this strategy for increasing my vocabulary taught me the denotations of words, I often failed to grasp the connotations.

In addition to the word *cheap*, another English word that causes connotation problems in scientific writing is *obvious*. While the denotation of the word *obvious* is "clear," the connotation is that the detail is so clear that only ignorant people will not know it. If the detail is in fact obvious, the question arises why you are placing the detail in the document. Moreover, if the detail is not obvious to the reader (the more likely case), then calling it "obvious" serves only to insult the reader.

A final source of imprecision, which is common among young engineers and scientists, arises from exaggeration. As an example, consider this sentence from a job application letter:

> I participated in countless activities.

The choice of the word *countless* sets off alarms for a scientific reader. Natural skepticism makes a scientific reader wonder whether the number of activities truly is *countless*—after all, counting is something that engineers and scientists do often and do well. Such imprecision undercuts the author's credibility. For instance, scientific readers might ask, if the author is stretching the truth on this point, what else is the author exaggerating? To avoid exaggeration, the author should write "many activities" or "several activities," depending on what the author's résumé reveals.

Another example of exaggeration occurs in the following example:

> Our thorough research of the literature revealed no such experiment.

Whether the research is "thorough" is the reader's call, not the author's. To avoid exaggeration here, the author should simply write, "Our research of the literature revealed no such experiment."

While high school writing teachers might have accepted or even praised such exaggerations, engineers and scientists view such words choices with scorn. In other words, although exaggeration might serve other types of writing, exaggeration undercuts credibility in scientific writing. Two words to take special care with are *prove* and *optimal.* Many engineers and scientists consider a geometric proof as the standard for using the verb *prove.* Likewise, scientific readers expect to see the maximum of a continuous function before accepting the adjective *optimal*.

## Avoid needless complexity

If I had only one piece of stylistic advice to whisper into the ear of every scientist and engineer, that advice would be "to avoid needless complexity." In my experience, needless complexity is the most egregious language problem in scientific writing:

> ***The Correspondence Principle.*** So far as the principles of the quantum theory are concerned, the point which has been emphasized hitherto is the radical departure from our usual conceptions of mechanical and electrodynamical phenomena. As I have attempted to show in recent years, it appears possible, however, to adopt a point of view which suggests that the quantum theory may, nevertheless, be regarded as a rational generalization of ordinary conceptions. As may be seen from the postulates of the quantum theory, and particularly the frequency relation, a direct connection between the spectra and the motion of the kind required by the classical dynamics is excluded but at the same time, the form of these postulates leads us to another relation of a remarkable nature.

This paragraph [4], written by the great physicist Niels Bohr, reveals needless complexities commonly found in scientific writing. One source of needless complexity occurs at the word level. For instance, in this example, we could find simpler substitutes for the words *hitherto*, *nevertheless*, and *generalization*. Another source of needless complexity in scientific writing occurs at the sentence level. In the Bohr example, the sentences average almost 40 words, which is too long. For clear writing, your sentence length in a document should average in the teens.

"Ah," someone will say, "but this writing is elegant and beautiful." Is it? The ideas are beautiful but the writing is murky, almost inaccessible. As Einstein said, "When you are out to describe the truth, leave elegance to the tailor" [5]. In scientific writing, beauty lies in clarity and simplicity. Consider the following revision to Bohr's paragraph:

> ***The Correspondence Principle.*** Many people have stated that the quantum theory is a radical departure from classical mechanics and electrodynamics. However, the quantum theory may be regarded as nothing more than a rational extension of classical concepts. Although no direct connection exists between quantum theory and classical dynamics, the form of the quantum theory's postulates, particularly the frequency relation, leads us to another kind of relation, one that is remarkable.

Although void of the original's needless complexity, this revision still conveys the intended ideas. As Einstein said with the phrase "yet no simpler," the writing has to convey the scientific content. For that reason, an underlying assumption in this section is that the revisions to the writing will still convey what was intended. As the cartoonist xkcd points out in the farcical *Up Goer Five Rocket*, which concerns the Saturn V Rocket, simplifying the writing too much leads to oversimplifying the content [6].

This section examines needless complexity at three levels: words, phrases, and sentences. Not explicitly discussed in this section is cutting needless words. As William Strunk maintains [7], omitting needless words also clarifies the language. However, this valued advice appears in Lesson 4: Sustaining Energy.

**Avoid needlessly complex words.** Many words used in scientific writing add no precision or clarity to the writing—only complexity. For instance, the needlessly complex word *elucidate*, which has four syllables, can be revised to *reveal*, which has only two syllables. Often, these needlessly complex words have distinguishing traits. For example, many needlessly complex verbs end in *-ize*. Although *–ize* verbs such as *minimize* and *maximize* are clear, many *–ize* verbs such as *prioritize* and *utilize* reduce to simpler forms: *rank* and *use*.

You might think that these substitutions do not make that much difference, and perhaps each individual substitution does not. Collectively, though, these substitutions have a profound effect. Consider the following sentence from a proposal in which the author consistently chose the needlessly complex word:

> The objective of this study is to develop an effective commercialization strategy for solar energy systems by analyzing the factors that are impeding early commercial projects and by prioritizing the potential government and industry actions that can facilitate the viability of the projects.

This sentence is inaccessible to readers. Are the words *commercialization*, *prioritizing*, *facilitate*, and *viability* necessary? Revision with attention to precision and clarity gives

> This study will consider why current solar energy systems have not yet reached the commercial stage and will evaluate the steps that government and industry can take to make these systems commercial.

Opting for these simpler word choices did not make the sentence simplistic. The sentence's idea had enough inherent complexity to surpass that label. Rather, opting for these simpler word choices made the content clear. In regard to the lengths of words, perhaps Winston Churchill said it best, "Short words are best and old words when short are best of all" [8].

One counterargument for relying exclusively on simpler words is that occasionally using a sophisticated word, such as *myriad*, shows the audience that you have a wide vocabulary, which in turn can increase your credibility. I agree. However, in being sophisticated, you need not be complicated. For instance, you need not show off your wide vocabulary in every paragraph. Perhaps a better frequency would be one such word per section. In fact, if you look at editorials in *The Wall Street Journal* or *The New York Times*, you will see that authors drop in sophisticated words such as *deleterious* but no more than one or two per editorial. After all, the writing still has to inform.

In addition, if you use a sophisticated word such as *comprise*, you need to ensure that the word is correct. As

Appendix C points out, the word *comprise* is misused much more often than it is used correctly. Finally, your sophisticated words need not be long. Rather than selecting a long word such as *exacerbate*, you can show that you have a wide vocabulary with short words such as *abate, deter, impede,* and *spate.* Although all of these words are old and have specific meanings, they are seldom written.

Long words are not the only type of words that add complexity. Run your eye over a page of a newspaper. Now run your eye over a page of writing from a scientific journal. Which page appears the more intimidating? The page from the journal probably does because of the typography inherent to science. Abbreviations, numerals, and strings of capital letters add complexity to writing. Although such typography is often needed in scientific documents, a significant portion of this complexity is not.

One unneeded complexity at the word level is needless abbreviation. An abbreviation often includes a period, which is the most powerful piece of punctuation. For the reader, a period is a stop sign: a two-space pause to absorb the idea of the last sentence. Reading a page that is cluttered with needless periods is similar to driving in the heart of a large city—stop, then go, stop, then go. Many of these abbreviations arise from Latin expressions: *exempli gratia* (e.g.), *et alii* (et al.), *et cetera* (etc.), and *id est* (i.e.). Just by knowing their English equivalents ("such as," "and others," "and other things," and "in other words"), you can write around them. Some abbreviations such as "in." or "fig." arise from editors who incorporate those abbreviations into their formats. I disagree with this practice, especially for short words. A period is much too valuable to spend on two or three letters.

A second source of typographical discontinuities is the use of needless capital letters. Granted, using capital letters in abbreviations such as DNA to represent a long term or such as IBM to represent a company name is often efficient for both the writer and the reader. However, using all capital letters for the names of projects (SOLAR ONE) or software (FLUENT) is needlessly complex. In the Bible, God settled for initial capital letters. Why should a project or piece of software deserve better treatment? No single typographical change slows the writing more than placing the letters in all capitals. Why? The reason is that people do not read every letter of a word. Rather, people recognize a word not only by the letters it contains but also by its shape. In other words, people recognize a word by seeing the shapes of the ascending letters (*b*, *d*, *f*, *h*, *k*, *l*, and *t*) and the descending letters (*g*, *j*, *p*, *q*, and *y*). However, when words are typeset in all capitals, the distinguishing shapes from ascenders and descenders are lost.

A third common source of needless complexity at the word level is the slash (/). The slash is an ugly piece of punctuation that adds unwanted complexity to the language. Examples include *he/she*, *s/he*, *w/o*, and *and/or*. For the first two examples, you can write *she or he* or you can use plural pronouns *(they, them).* In the case of *w/o,* simply write *without.* Finally, in the case of *and/or,* which no doubt a lawyer created, using either *or* or *and* suffices most of the time. For those cases in which both are required, you should rely on plain English:

> Detection calls for an ultrasound or EKG or both.

You should apply the same stylistic strategy for other concocted slashed terms. In other words, do not write

> …impact/influence on reservoir quality…
>
> …difficult/misinterpreted measurements….

Instead, either choose one of the terms or use a conjunction to connect the terms:

> …influence on reservoir quality…
>
> …difficult or misinterpreted measurements….

**Avoid needlessly complex phrases**. Another source of needless complexity occurs in phrases in which the author strings modifiers in front of nouns. Because nouns, particularly subject nouns, are stepping-stones in sentences, stringing adjectives and other nouns acting like adjectives in front of those subject nouns confuse readers. Readers do not know where to step:

> Solar One is a 10-megawatt solar thermal electric central receiver Barstow power pilot plant.

Say this sentence aloud. Did you lose your breath before finishing? If all these modifiers are important, then the engineer should either place them in phrases and clauses around the principal noun *plant* or work them into multiple sentences:

> Solar One is a solar-powered pilot plant located near Barstow, California. This plant produces 10 megawatts of electric power by capturing solar energy in a central receiver design.

Stringing modifiers in front of nouns also dilutes the meanings of the modifiers. The modifiers become lost in the string. Moreover, long strings insert ambiguity into sentences:

> The decision will be based on economical fluid replenishment cost performance.

What exactly does the phrase *economical fluid replenishment cost performance* mean? Will the decision be based on the performance of the fluid or on the cost of replacing the fluid? Or on something else? Pursuing our goals of precision and simplicity, we revise this sentence to

> The decision will depend on the cost of replacing the thermal oil.

**Avoid needlessly complex sentences**. As has happened to many students in engineering and science, the first day I began graduate school, my research professor gave me a stack of journal articles to read. From the top paper of that stack, the third sentence read as follows:

> The object of the work was to confirm the nature of electrical breakdown of nitrogen in uniform fields at relatively high pressures and interelectrode gaps that approach those obtained in engineering practice, prior to the determination of the processes that set the criterion for breakdown in the above-mentioned gases and mixtures in uniform and non-uniform fields of engineering significance.

This sentence stopped me cold. I could not figure out what it was saying. Such a sentence imposes a barrier for readers. Why? One reason is the length: 61 words. That is long. A typical sentence length would be in the teens. Even more of a problem, the sentence tries to communicate multiple ideas. As

Theodore Bernstein, former editor of *The New York Times*, enjoined his writers: "One idea, one sentence" [9].

Still another problem with this sentence is that the reader has no early clue that the sentence will be long. The sentence could have logically ended after the thirteenth word *breakdown*. Instead, the sentence lumbers from one prepositional phrase to another. Prepositional phrases are important because they incorporate details of time, manner, and place. This sentence, however, has 11 prepositional phrases. Count them—11. In this sentence, the prepositional phrases are stacked like boxcars on a train. They provide no momentum, only friction. Because this sentence has this unbroken stack of boxcars, the sentence feels long about halfway through, which is only 25 to 30 words.

Now, you can write a sentence of 25 to 30 words without that sentence feeling long. To do so, though, you have to give the reader an early clue that the sentence will be long. One way to do that is to start the sentence with a ***dependent clause***. For instance, a sentence that begins with *although* signals the reader that the sentence will have two parts: (1) a dependent clause beginning with *although* and ending with a comma, and (2) an independent clause that typically runs the same length. Because dependent clauses often are 10 to 15 words, when a reader sees that a sentence begins with *although,* the reader already expects the sentence to run 20 to 30 words.

How should the original sentence be revised? First, the revision should break the original sentence into smaller sentences: one for each idea. For the first idea, a first revision could be

> At relatively high pressures and typical electrode gap distances, the electrical breakdown of nitrogen was studied in uniform fields.

This revised sentence has 23 words, which is a relatively long sentence. Nevertheless, the sentence succeeds. Instead of eleven prepositional phrases, the sentence has only three.

While this first revision succeeds, a second revision is worth the effort:

> This study tests the electrical breakdown of nitrogen in uniform fields. For these tests, the electrode gap distances were typical, while the pressures were relatively high.

Although this second revision uses more words, this revision assigns much better emphasis to the details. Not only does the reader learn what the study does but the reader also gathers what distinguishes this study: the relatively high pressures at which the tests occurred.

In general, the more complex the original idea is, the more revisions that are needed to clarify that idea. A misconception held by many engineers and scientists is that the best writers create their writing in a single draft. The truth is that professional writers produce more drafts than typical writers do. For instance, the great short story writer Raymond Carver claimed to have drafted many of his short stories 30 times before being satisfied [10]. Although scientific writing differs much from fiction writing, the amount of revision by Carver and many other professional authors serves notice that excellence in writing does not occur on the first draft.

Consider another needlessly complex sentence from an engineering report:

> To separate the hot and cold oil, one tank was used that took advantage of the thermocline principle, which uses the rock and sand bed and the variation of oil density with temperature (8% decrease in density over the range of operating temperatures) to overcome natural convection between the hot and cold regions.

Although this sentence provides clues up front that the sentence will be long, the sentence does not inform efficiently. The engineer has confronted the reader with several ideas but allows the reader no break to comprehend each idea.

Before improving this sentence, you should decide which details in the sentence are important. Does the reader need to know how the hot and cold oil are separated, how the density varies in the tank, or what the thermocline principle is? If these details are not important, then delete them. However, if the reader needs to know these details to understand the work, then you should allot at least one sentence to each idea.

> The question was how to separate the hot and cold oil in the rock and sand bed. Rather than have one tank hold hot oil and another tank hold cold oil, we used a single tank for both. This design took advantage of the variation of oil density with temperature. In our storage system, oil decreases in density by 8% over the range of operating temperatures. This variation in density allows the hot oil to float over the cold oil in the same tank. Natural convection is impeded by the position of the hot oil over the cold and by the rock and sand bed. Therefore, the heat transfer between hot and cold regions is small because it occurs largely by conduction. The concept of storing heat in a single vessel with hot floating over cold is known as "thermocline storage."

Besides being much clearer, the revision makes strong links between each idea and positions unfamiliar terms such as "thermocline storage" at the ends of sentences, rather than at the beginnings.

So far, we have discussed complexity in a qualitative way. Interestingly, you can quantitatively measure the complexity of writing. The most well-known equation for measuring the complexity index for a piece of writing is the ***Gunning Fog Index***, $F_i$:

$$F_i = 0.4\left(\frac{N_w}{N_s} + P_{lw}(100)\right),$$

where $N_w$ is the number of words in a typical paragraph, $N_s$ is the number of sentences in the paragraph, and $P_{lw}$ is the percentage of long words (three or more syllables) in the paragraph [11]. In counting the number of long words, this index calls for not counting the following: the first word of the sentence, no matter what the word is; proper names (such as *California*); and verb forms that acquire the third syllable from an *-ing* or *-ed* ending.

Such a measure provides insight into what causes a piece of writing to be complex—namely, the lengths of the sentences and the lengths of the words. Although you might not have not heard of the Gunning Fog Index, you are familiar with calculations using this index, because these calculations are cited as the "reading level" of a document. For instance, *USA Today* has a reading level (or index) of 10, *The Wall Street Journal* has a level of 11, and *Scientific American* has a level of 12.

Note that reading level is a measure of the complexity of the writing, rather than the complexity of the content. Just because a document, such as Einstein's *Special Theory of Relativity*, has a reading level of 12 does not mean that a senior in high school will understand the document. What a reading level of 12 means is that a typical twelfth grader in the United States would feel comfortable with the lengths of the words and sentences.

In your writing, you should aim for a reading level between 10 and 13. For a professional reader, such a reading level is efficient. If the reading level is too low, too many sentences would be short, making the writing choppy. If the level is too high, the reader focuses too much of her or his attention on how the document is written, as opposed to what ideas the document contains.

For engineers and scientists, the main challenge is avoiding reading levels that are too high. For instance, the reading level of the Niels Bohr paragraph at the beginning of this section is 24. Facing a passage with a reading level of 24, the reader has to focus so much attention on understanding the long words and parsing the long sentences that the reader has little focus left for comprehending the ideas.

As the example by Niels Bohr reveals, you should take care in choosing your models for scientific writing. Niels Bohr was a great scientist and a compassionate soul but he was not a great writer. Much better models would be Maria Goeppert Mayer, Albert Einstein, Gertrude Elion, Stephen Hawking, or Jane Goodall.

When writing, you should imagine yourself sitting across from your most important reader. Write your paper as if you were talking to that reader. This strategy does not mean that your writing should be informal. Rather, it means that you should rid your writing of needless formality. The purposes of scientific writing are to inform and to persuade—not to impress.

## Balance precision and clarity in illustrations

Just as a balance of precision and clarity is important in your written words, so too is that balance important in your illustrations. Put simply, the precision of your illustrations should reflect the precision of your language. A common mistake in scientific writing is to present a figure that is much more complex than the text:

> The thermal storage system stores heat in a huge, steel-walled insulated tank. Steam from the solar receiver passes through heat exchangers to heat a thermal oil, which is pumped into the tank. The tank then provides energy to run a steam generator that produces electricity. Figure 2-1 shows a schematic of this system.

Figure 2-1 is just too complex for the accompanying text. Perhaps you could include this schematic in an appendix for readers who are already familiar with the system but in the general discussion, you should use an illustration such as Figure 2-2 [12].

Although Figure 2-2 includes temperatures that are not explicitly mentioned in the text, these details are self-explanatory. Moreover, these temperatures serve the document

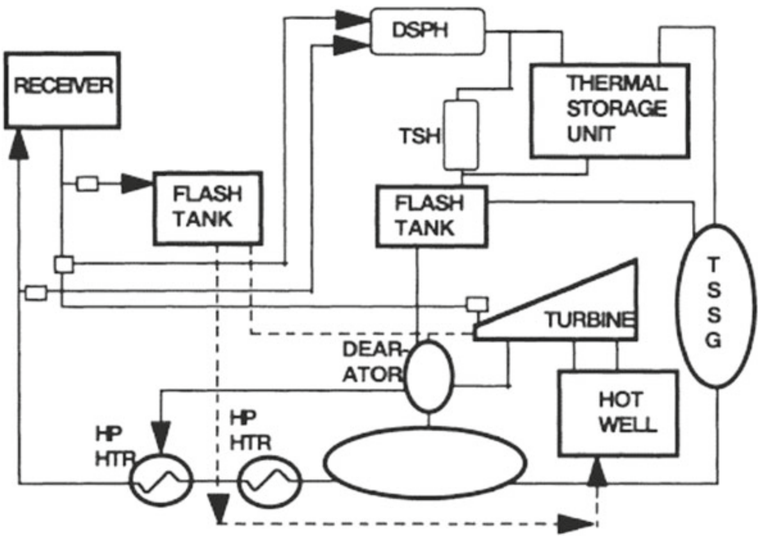


**Figure 2-1.** Thermal storage system.

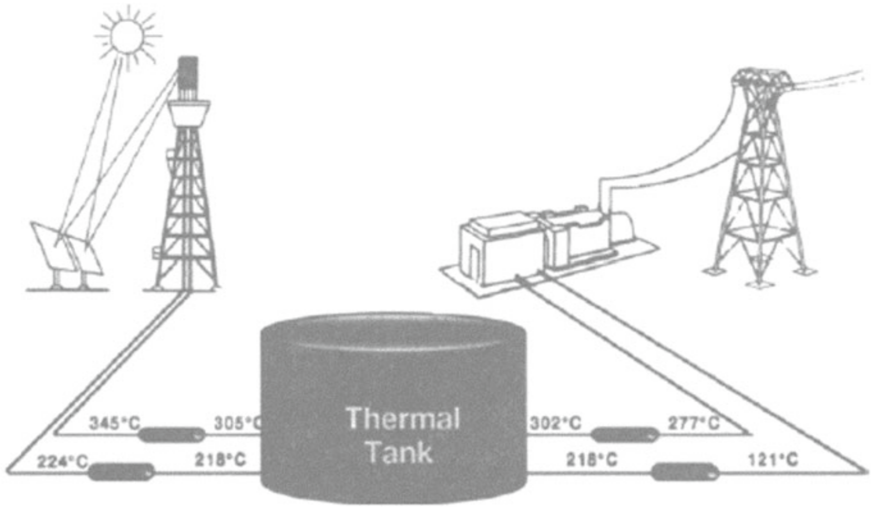


**Figure 2-2.** Thermal storage system. This storage system takes excess energy from the solar receiver and stores it for later use when the sun is no longer providing solar radiation to the mirrors.

because the document's paragraphs following the introduction of this figure discuss these temperatures.

Too often in scientific writing, illustrations confuse rather than inform. Many scientists and engineers mistakenly assume that an illustration is worth a thousand words. Not so. A picture or photograph may raise more questions than it answers. Figure 2-3 supposedly shows a chemical reaction driven by solar energy but all you can tell from this photograph is that the reaction is bright. This photograph does not focus attention on the experiment. Instead, extraneous details stand out. For instance, is the lab always this messy? Does this guy really wear that white lab coat? Exactly what is written on the clipboard?

Figure 2-4, on the other hand, is an illustration worth a thousand words [13]. Figure 2-4 shows the main gas flow through a jet engine. Although a jet engine is inherently complicated, this drawing emphasizes the most important details with no lab coats or clipboards vying for attention.

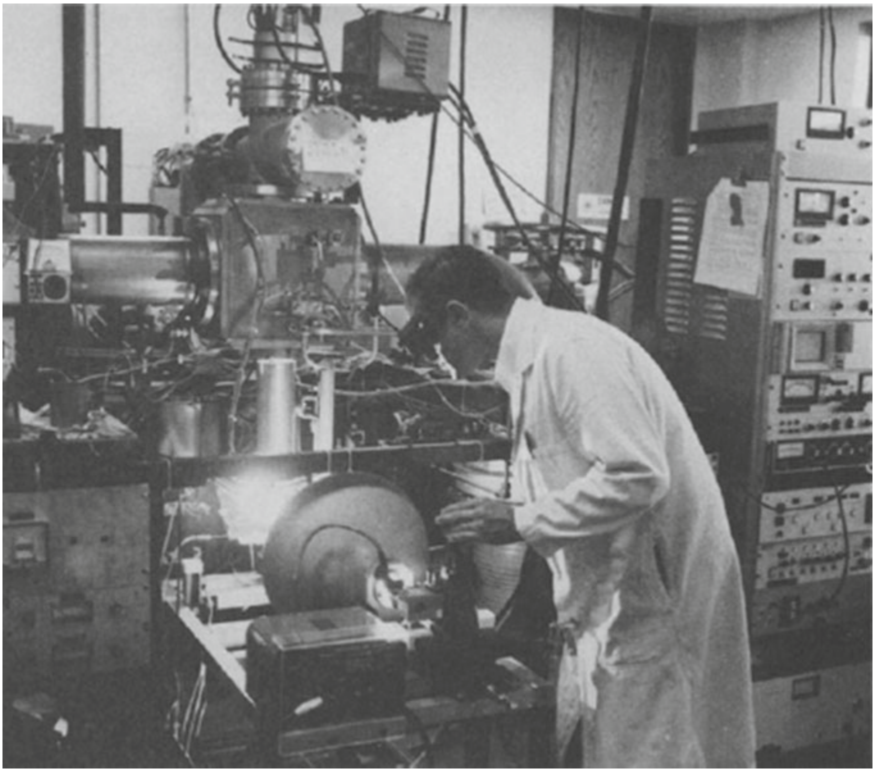

**Figure 2-3.** Photograph that allegedly shows a chemical reaction driven by solar energy. The background overshadows the central image.

Unclear illustrations arise not only because of mistakes in the selection of illustrations but also because of mistakes in the language that introduces and labels the illustration. Illustrations cannot stand alone. You need language to mesh the illustration into the document. When you introduce an illustration, you should assign it a formal name and provide enough information, either in the text or in the illustration's caption or heading, that readers can understand what the illustration is and how it fits into the document.

Besides introducing illustrations in the text, you should identify illustrations with a caption or heading. A well-written caption or heading not only identifies the illustration but also

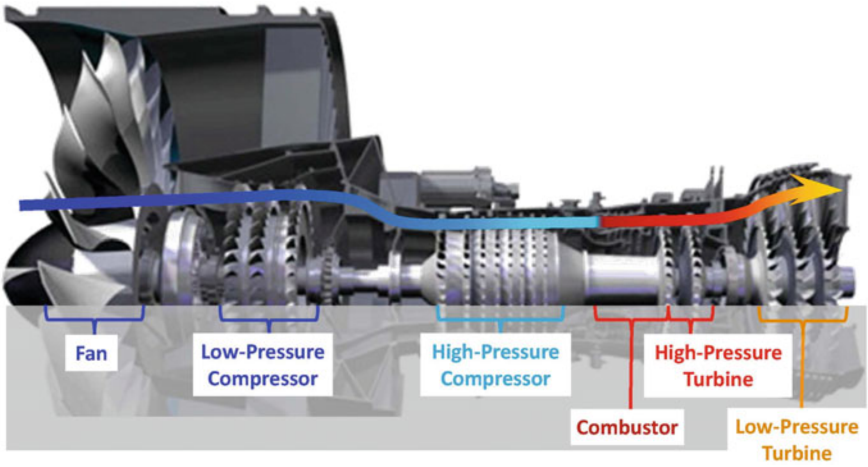


**Figure 2-4.** Cutaway drawing of a jet engine produced by Pratt & Whitney. The colored line shows the flow of fluid through the main parts of the engine: compressor, combustor, and turbine. In addition, the color reflects the temperature of that fluid is (with blue representing cooler temperatures and red representing hotter temperatures).

answers immediate questions that the illustration raises. When readers turn a page, their eyes naturally move first toward the illustrations. If those illustrations are interesting, readers often look at the illustrations' captions or titles before continuing to read the text. Therefore, you want your figure captions and table titles to provide enough information to stand independent of the text.

Typically, in captioning an illustration, you begin the caption with a title phrase that identifies what the illustration is. In writing this title phrase, you should give the same kind of consideration that you give to the title of the document. In other words, you should choose a title that identifies what the illustration is and provides enough information to separate this illustration from all the other illustrations in the document. Also, in many report formats, you have the opportunity in a figure caption to provide an additional sentence or two that clarifies unusual details. In such cases, you should seize the opportunity. The following example shows an introduction and caption for a photograph of a solar power plant (Figure 2-5). In this example, the writer uses those extra sentences in the caption to explain the unusual bright streaks in the photograph [14].

> In the Solar One Power Plant, located near Barstow, California, and shown in Figure 2-5, a field of sun-tracking mirrors, or "heliostats," focuses reflected sunlight onto a solar-paneled boiler, or "receiver," mounted on top of a tall tower. Within the receiver, the solar energy heats a transfer fluid that drives a turbine. Coupled to the turbines are generators that the produce electricity. Also included in this system is a thermal storage system that can operate the plant for several hours after sunset or during cloudy weather. The maximum power output from this plant is 12.2 megawatts.

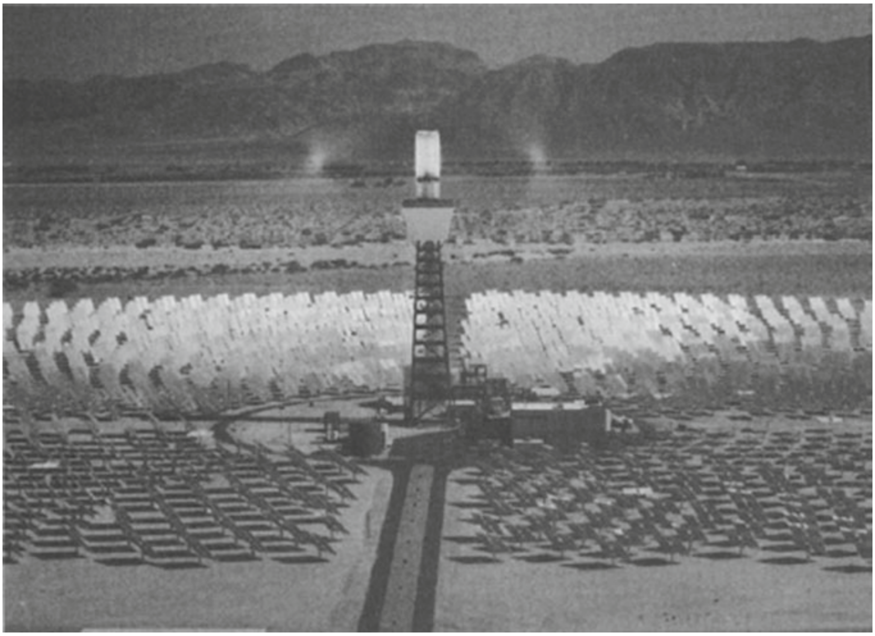

**Figure 2-5.** Solar One Power Plant located near Barstow, California. The bright streaks on either side of the receiver are standby points to prevent the mirror beams from converging in the airspace above the plant when the plant starts up each day.

## References


1. Albert Einstein, quotation attributed by Hans Byland (1928). Original text: *"Schreibe ich zu kurz, so versteht es überhaupt niemand; schreibe ich zu lang, so wird die Sache unübersichtlich."* This quotation has a number of forms and appeared to be an idea, dubbed Einstein's razor, that Einstein revisited a number of times.
2. Mark Twain, attributed.
3. Inspired by a "Mathematical Recreation" article in *Scientific American*.
4. Niels Bohr, *The Theory of Spectra and Atomic Constitution* (Cambridge: Cambridge University Press, 1924), p. 81.
5. Albert Einstein, in *eine dokumentarische Biographie*, by Carl Seelig (Vienna: Europa-Verlag, 1954), p. 168. Original text: "*Die Schönheit, meine Herren, wollen wir den Schustern und Schneidern überlassen. Unser Forschungsziel muß die Wahrheit bleiben*."
6. xkcd, "Up Goer Five," *xkcd: a webcomic of romance, sarcasm, math, and language,*http://xkcd.com/1133/.
7. William Strunk and E.B. White, *The Elements of Style*, 4th ed. (New York: Pearson, 1959).
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9. Theodore Bernstein, *The Careful Writer* (New York: Free Press, 1995).
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11. Robert F. Gunning, "The Fog Index after Twenty Years," *Journal of Business Communication*, vol. 6, no. 2 (1969), pp. 3–13.
12. L. G. Radosevich, *Final Report on the Experimental Test and Evaluation Phase of the 10 MWe Solar Thermal Central Receiver Pilot Plant*, SAND85-8015 (Livermore, CA: Sandia National Laboratories, 1986), p. 43.
13. J. Gibson, K. A. Thole, J. Christophel, C. Memor, and T. Praisner, "Pressure Distortion Effects on Rim Seal Performance in a Linear Cascade," *International Gas Turbine and Aeroengine Congress and Exposition*, Seoul, South Korea, GT2016-58098, 2016.
14. Patricia K. Falcone, *Handbook for Solar Central Receiver Design*, SAND86-8006 (Livermore, CA: Sandia National Laboratories, 1986).

conclusions was that two O-rings, which were secondary seals to prevent the fuel from escaping, had failed [2].

Seven years before that fateful launch, a NASA engineer had reservations about the O-ring design of the shuttle's solid rocket boosters. After learning about those reservations, NASA management requested that the engineer seek opinions from O-ring experts about the design. From visits to two large manufacturers of O-rings, the engineer found that both manufacturers also held serious concerns about the design [2]. In fact, one manufacturer expressed surprise that the O-ring design had performed so well. To document the trip, the engineer wrote a short report to NASA management with the following title:

> Subject: Visit to Precision Rubber Products Corporation and Parker
> Seal Company

This title is weak. Why? Put simply, this title did not reveal to the audience what the report was about.

A careful author would have thought more deeply about the audience. For example, would NASA managers have remembered their request 3 weeks before to seek opinions from O-ring experts? Perhaps. Would this audience have recognized those two companies as large manufacturers of O-rings? Probably not. Would the audience have realized the connection between those two companies and the concern raised about the O-ring design in the shuttle's solid rocket booster? Doubtful.

Someone attuned to the audience of this report would have crafted a much different title:

> Subject: Concern by O-ring Manufacturers about the Secondary Seal
> Design in the Shuttle's Solid Rocket Boosters

Giving such care to the titles of scientific documents is important. Titles strongly influence whether the audience will read, file, or discard the document. We do not know whether a stronger title would have made a difference with this short report. What we do know was that this report was the end of the paper trail for NASA's concern about this O-ring design. In other words, no one responded in writing to this report, even though the report contained strong warnings about the design [2].

Your understanding of the audience is essential for your success as an author.

Before spending the energy to write sentences in a scientific document, you should analyze the document's audience. In addition, you should analyze two other constraints of the document: purpose and occasion. These three constraints—audience, purpose, and occasion—greatly affect the style of scientific writing. For instance, audience affects which terms you define, what background information you provide, and which details you emphasize. Likewise, the purpose shapes your sentences and paragraphs. If you are simply informing such as in a set of instructions, you might arrange the ideas in a numbered list. However, if you are fashioning an argument such as in a proposal, you would want to connect the ideas in full-fledged paragraphs. Occasion also affects the style of your writing. For instance, the writing style of a researcher in medicine who has only two pages to write a paper will differ significantly from the writing style of a geologist who has twenty.

## Analyze who your audience is, why they are reading, and what they know

In a scientific document, the audience affects every sentence and image. Compared with other types of writing such as journalism, scientific writing targets audiences with much wider ranges of familiarity with the content. In other words, while a sports reporter for a newspaper targets an audience with the same general understanding of a sport, an engineer or scientist often faces audiences with widely different levels of understanding about the subject.

Assume for the moment that you are an engineer who has used electronics from space exploration to design an implant to deliver insulin to diabetics [3]. 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 who are 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 essentially the same content but three different audiences and three distinctly different documents.

With each document, you should assess the following three questions about audience:

(1) who is the audience?
(2) why is the audience reading?
(3) what does the audience know?

Answering the first question of *who the audience is* reveals how challenging the document will be to write. In more straightforward cases, you have only one type of reader, such as a technical manager. In more difficult situations, you have a mixture of audiences: engineers and scientists in your field, engineers and scientists from other fields, and managers. In still more difficult documents, that varied audience might include people with no background in science—politicians, for example.

Answering the second question of *why the audience is reading* tells you what information the audience needs or wants. Knowing that, you can define the document's scope: what work to include and what to leave out. In addition, you can determine which findings to emphasize. As Professor Andrew Zydney pointed out in the chapter's opening quotation, many engineers and scientists neglect to address this question. For that reason, many documents are doomed from the start because the author buries or perhaps does not even discuss what the audience considers most important.

Answering the third question of *what the audience knows* about the content helps you decide which order to arrange the content, which terms to define, and what background to include. When you have a mixture of audiences, you should assess which readers are your primary audience. That assessment is important for structuring the document. For instance, in a formal report, you target the primary audience in the main sections and then use appendices and perhaps a glossary to reach secondary audiences.

For documents that contain unexpected or controversial findings, you should explore this third question at a deeper level by also considering what the audience *believes* about the content. In particular, you should consider the audience's initial bias toward your conclusions. With an audience holding a neutral stance about your conclusions, an assertion-evidence approach works well [4]. In this approach, you build an argument on assertions (or claims) that are supported by evidence from your theories, computations, and experiments. However, relying solely on an assertion-evidence approach often falters if the audience holds a deep-seated biased against your conclusions. In such cases, you would do better to craft an argument that first shows your understanding of the audience's initial position on the question [5]. Then you present your evidence for the question, before revealing your stance (or assertion) on the question. Ideally, the evidence reveals not only the weaknesses of the audience's initial position but also the logic of your conclusion. Although this second evidence-assertion strategy will not necessarily win over opponents with strong biases [5], those opponents are more likely to read further in the document. In addition, those readers are more likely to appreciate your position.

## Analyze how much persuasion your document requires

Besides audience, another important constraint for a scientific document is the purpose. In scientific writing, you write for two specific goals: to inform and to persuade. All scientific documents have the first goal: to inform. Concerning the second goal, the level of persuasion varies widely across documents. For instance, a set of instructions carries relatively little persuasion, while a proposal carries a high degree of persuasion.

To understand the role of purpose in scientific writing, a helpful analogy is to think of your scientific documents as paths up your mountain of expertise. Here, you as the author try to lead audiences to vistas of understanding about your work. In this analogy, depicted in Figure 1-1 when the purpose of the writing is purely informative, you can think of the trail as a smooth dirt path, such as through a meadow. When the process is complex, the trail might be steep but the path remains smooth. No matter whether the slope is gentle or steep, with purely informative writing, your goal is straightforward: to provide the *what, where, when,* and *how* of the content so that the audience can follow your path. In such writing, the key measure for success is efficiency, which is how quickly your writing leads the audience from one point to another.

**Figure 1-1.** Mountain path as an analogy of the author's path in an informative document [6]. In this analogy, the more technical the content, the steeper the slope of the path.

When the purpose of your writing includes persuasion, another measure for success comes into play: your credibility. For such writing, it is not enough that the audience simply understands your content. In such writing, the audience continually questions your content and therefore is interested not only in the *what*, *where*, *when*, and *how* but also the *why*. For that reason, persuasive writing calls on you to balance being efficient with being credible. Put another way, in persuasive writing, you spend additional words to build your credibility with the audience. In our analogy, depicted in Figure 1-2, a persuasive portion of a trail would be rocky, such as a boulder field. In a boulder field, a hiker does not take every step in the direction of the summit. Rather, the hiker takes additional steps to navigate around the boulders. Likewise, in a persuasive document, some sentences that you write are not to aid the audience's understanding but to build your credibility.

In a similar way that audience affects the style of writing, so does purpose. For instance, consider the style of instructions, which are predominantly informative with relatively little persuasion. This writing style often reduces to numbered lists

**Figure 1-2.** Boulder field as an analogy of the author's path in a persuasive document [7]. Just as a hiker in a boulder field chooses paths around the steep rocks, an author in a persuasive document spends words to build credibility with the reader.

of steps that are separated by white space and arranged vertically down the page. How does this choppy style serve instructions? When reading instructions, the reader typically reads a step, turns from the document, and then performs the step. In a vertical list of steps, the reader can quickly find the next numbered step because it stands apart from the others.

While the style of having vertical lists serves the purpose of instructions, this style is not effective in persuasive documents. When reading an argument, the audience expects strong links between the ideas. For that reason, persuasive writing calls for full-fledged paragraphs. Unfortunately, many engineers and scientists fail to realize this difference in style. Rather, these authors litter their persuasive reports with vertical lists that disrupt the continuity and do not show the connections.

In addition, the paragraphs of persuasive writing are typically longer than paragraphs of primarily informative writing. One reason is that in persuasive writing, the author addresses the question of *why*. For instance, in a proposal for an experiment that measures blood flow through a heart valve, the reader cares deeply not only about what measurement technique the author has chosen but also why the author selected that technique. Such a choice warrants an explanation, which leads to longer paragraphs.

## Account for the document's occasion: the form, formality, and politics

Just as audience and purpose often vary from document to document, so does occasion. Occasion encompasses the form of the document, the document's formality, and the politics surrounding the content. Each of these three aspects can significantly affect the writing.

**Form.** In scientific writing, form comprises not only the rules of grammar, punctuation, usage, and spelling but also the guidelines for length and format. Among these aspects of form, one category that invokes fear in many authors, but should not, is grammar. Essentially, grammar concerns the rules for arranging words into meaningful sentences. Compared with other languages such as Polish, English has relatively few grammatical rules. In English, the most important rule of grammar is the definition of a sentence: a group of words with a subject and verb that gives a complete thought.

Certainly, engineers and scientists should know grammar well enough that they do not make grammatical mistakes, such as a ***fragment*** or ***run-on sentence***. However, another important goal is to understand grammar well enough to write sophisticated sentences—sentences that connect ideas in efficient ways, that emphasize important details, and that produce enough variety to drive readers through longer documents. For such an understanding of grammar, you should be able to recognize the basic parts of speech: ***noun, pronoun, verb, adjective, adverb, preposition,*** and ***conjunction***. If you can recognize these parts in sentences, you are in a position to analyze your own writing of sentences to achieve a sophisticated style. Presented in Appendix A is a synopsis of grammar for such an understanding.

Although the grammar of English has relatively few rules, the punctuation of English contains many. Each piece of punctuation, be it a comma, period, colon, or ***em-dash***, carries its own set of rules. For a comma, not only do many rules exist but a good portion of those rules fall into a gray area. In other words, in many situations, whether to insert a comma is optional. Presented in Appendix B are the most important rules for punctuation in scientific writing.

Even more rules exist for English usage, which concerns the way we use words. Usage encompasses which word (for example, *affect* or *effect*) to use, whether to use a singular or plural, and which verb tense to select. Because English contains words from so many different languages, many exceptions for these decisions exist, and these exceptions lead to common misconceptions. As one small example, the word *plethora* does not mean "an abundance," as many authors assume, but "an overabundance." To become sensitive to the most common usage mistakes in scientific writing, see Appendix C.

In English, confusion about punctuation and usage sometimes arises because of location. For example, in the United States, end quotation marks appear outside of periods and commas. However, in Great Britain, end quotation marks usually appear inside periods and commas. Likewise, in most publications such as *Scientific American*, the years from 1990 until 1999 are written as the *1990s*, while in *The New York Times*, those years are written as the *1990's*. A third challenge for punctuation and usage in English is that rules sometimes change with time. For instance, in the 1920s, Roentgen rays were written as *X rays*. Today, however, *x-rays* is proper. In addition, because of changes in pronunciation, while *an historical* was proper form in the 1700s, *a historical* is proper today. No simple advice exists to handle the maze of punctuation and usage rules in English. As a writer, you have to distinguish between rules without exceptions, such as the spelling of the word *separate*, and rules with exceptions such as when to use numerals and when to write out numbers.

The effect of document length, which is another aspect of form, is relatively straightforward. The shorter the document is, the less depth that you can achieve. For instance, the page limits of a journal paper might allow you only one sentence to justify the importance of your work:

> The cooling of blades in gas turbine engines is important because the combustion gases that flow over the blades are more than 500 °C hotter than the blades' melting temperature [8].

In a report or thesis, though, you would likely have more space to make this same argument:

> The cooling of blades in gas turbine engines is important because the combustion gases that flow over the blades are more than 500 °C hotter than the blades' melting temperature [8]. In addition, these blades are expensive, often costing more than $25,000 for the replacement of each blade. Moreover, cooling can make a significant difference in a blade's life. For instance, reducing the temperature on a gas turbine blade by just 25 °C doubles the blade's life [9].

In this second argument, the additional space allowed the author to deepen the argument.

Format, which is yet another perspective on form, is the way that you arrange the type on the page. Format includes such decisions as the typeface selected, the number of columns, the way to number the pages, and the way to reference sources. No universal format exists for scientific writing. Because journals, laboratories, and corporations establish their own formats, the formats of science vary widely. A number of engineers and scientists fret over things such as why Journal A has one type of referencing system, while Journal B uses another. Instead of worrying about a journal's format, over which you have no control, you should worry about style, which is something you do control. For example, you should worry about your word choices, the complexity of your illustrations, and the way you emphasize your results.

In many situations such as writing a journal paper, the format is set. In other words, you are expected to follow the established guidelines. However, situations arise such as an unsolicited proposal in which you select the format. For such situations, you should consult a graphic designer. For situations in which no graphic designer is available, Appendix D presents general recommendations for formatting scientific documents to achieve a professional look.

**Formality.** In addition to form, the formality of an occasion influences the way that you write. Compared with fiction and journalism, scientific writing is formal. Presented in Table 1-1 are words and expressions that many scientific readers see as too informal. For instance, while the expressions *a lot* and *get* are fine when spoken, these expressions when written unsettle some readers. As another example, while beginning a sentence with the conjunction *but* is now allowed by many newspapers, the practice is still too informal for scientific writing. Most scientific editors would expect that you select the adverb *however* (followed by a comma) to begin such sentences.

**Table 1-1.** Expressions considered to be too informal for scientific writing

| Too Informal | Accepted |
|---|---|
| *a lot* | *much* or *many* |
| *get* | *obtain* |
| contractions (*don't*) | written out (*do not*) |
| *And....* | *Also,....* |
| *But....* | *However,....* |
| *vs.* | *versus* |
| *&* | *and* |
| *you** | *one* |

*Accepted in correspondence and instructional texts but not in articles or reports

Other expressions such as *vs.*, *&*, and *you* are accepted on certain occasions but not in others. While the abbreviation *vs.* is appropriate in a table column that has limited space, you should write out the abbreviation when space allows. Likewise, while an ampersand is fine to use when part of a company name (*PG&E*, for instance), you should not substitute it for the word *and* in a sentence. Such a substitution borders on graffiti. Finally, while the word *you* is appropriate in correspondence and instructions (including this book), readers consider the use too informal for a journal article, formal report, or dissertation.

**Politics.** Yet a third way that occasion influences scientific writing is through politics. In an ideal world, politics 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 engineers and scientists are often constrained in their writing not only by the need to remain honest but also by the need to satisfy administrators. Illustrating this point is the poor communication between engineers and NASA the day preceding the fateful launch of the Space Shuttle Challenger. Months before the accident, engineers at Morton Thiokol International, a contractor for the shuttle, not only knew about the erosion of the O-rings in the solid rocket booster's joints but also had evidence that lower temperatures would exacerbate this problem [2]. When temperatures plunged below freezing the day before the fateful launch, the engineers tried to have the launch stopped. However, they were rebuffed by NASA officials at Marshall Space Center. Why? One reason was the politics surrounding the shuttle launches at that time. Because of delays in previous launch attempts, NASA was under political pressure to launch. In addition, because NASA had a reputation for firing contractors who admitted the technical problems in their designs, Morton-Thiokol had avoided informing NASA about their concerns with the O-ring erosion.

Political pressures affect most documents to some degree. In dramatic cases, such as the Space Shuttle Challenger, the political constraints force you to face your ethical responsibilities as an engineer or scientist and to act accordingly. In most cases, the stakes are not nearly so high. In cases with lower stakes, the important thing is that you distinguish between the political constraints imposed on that document and the stylistic goals desired for the rest of your writing. For instance, just because a company lawyer insists that you be wordy in a report's disclaimer does not mean that wordiness is desired in the rest of your writing.

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# Avoiding Ambiguity

*The disastrous charge of the Light Brigade at Balaclava in the Crimean War was made because of a carelessly worded order to 'charge for the guns'—meaning that some British guns which were in an exposed position should be hauled out of reach of the enemy, not that the Russian batteries should be charged. But even in the calmest times it is often difficult to compose an English sentence that cannot possibly be misunderstood* [1].

—Robert Graves and Alan Hodge

An ambiguity is a word, phrase, or sentence that readers can interpret in more than one way. In poetry, readers celebrate ambiguity. For instance, critics delight in the ambiguity of the last two lines of a poem by e. e. cummings about Buffalo Bill Cody [2]:

How do you like your blue-eyed boy
Mister Death

Is the poem a eulogy to a western hero or a condemnation of all the animals that he killed? In other words, does "Mister Death" at the end of the poem refer to a spirit or to Buffalo Bill himself? Because of the lack of punctuation, these last two lines can be read in two distinct ways. Like poetry, art also finds delight in ambiguity, such as in the Escher-like facade of Figure 3-1 [3]. Here, the ambiguity lies in whether the lizards are gold or white.

Although ambiguity is cause for celebration in poetry and art, ambiguity frustrates a scientific reader:



M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_3

**Figure 3-1.** Ambiguity in a building's façade, which follows a design by Escher. Are the lizards gold or white?

The solar collector worked well under passing clouds.

Does the solar collector work at a height that is well below the passing clouds, or under passing clouds, does the solar collector work well? Such an ambiguity leads audiences to waste time by having to reread a passage to discern the correct meaning. Other ambiguities, particularly in instructions, can lead readers to make errors, which in technical instructions can lead to failure of a structure or injury to a person. While poets and artists garner praise for ambiguities, engineers and scientists receive lawsuits.

So how do you avoid ambiguities in scientific writing? Before addressing that question, let us consider the following excerpt from a report submitted by an engineer:

> ***Radiometer System.*** Two general requirements to be met are (1) to survive and accurately measure the radiation incident on the receiver and (2) to present the data in a form that can be used to verify computer code predictions.

Three ambiguities riddle this description. First, are the general requirements for the radiometer system or something else? Second, in the first requirement, who or what must survive? A third ambiguity concerns the number of requirements, because the first requirement has two criteria. In this excerpt, haste on the author's part most likely led to these ambiguities. Attention to precision and clarity gives the following revision:

> ***Radiometer System.*** The radiometer system for the solar receiver has to meet three requirements. First, the system's electrical components have to survive in solar radiation as intense as 300 kilowatts per square meter. Second, the system has to measure to within 5 percent the solar radiation on the receiver. Third, the system's output has to verify computer codes.

Ambiguities are difficult to catch on first drafts when your focus is on placing complex ideas onto paper. Rather, the best time to catch ambiguities is during the revision stage when you can view the writing as your readers will.

Some engineers and scientists lament about how tired they are after writing a first draft. "I cannot look at it anymore," they say. "It is too painful." Perhaps the writing is painful, especially if it was drafted with the same lack of clarity as in the radiometer example above. However, the writing represents your work, and if you spent significant time and effort doing the work, then you should also spend a reasonable amount of time and effort documenting the work. Attaining clarity does not occur on first drafts when you have a blank computer screen staring at you. Rather, you attain clarity on later drafts when you have your ideas, calculations, and measurements in front of you. Although the ambiguities in the radiometer example are difficult to classify, many ambiguities arise from four specific sources: word choice, word order, pronouns, and punctuation.

## Avoid words with multiple interpretations

Many words in English have multiple meanings. For instance, the word *right* has a meaning referring to "correctness" and another meaning referring to "direction." In most instances, the intended meaning of such words are clear. However, in scientific writing, situations arise in which using such words leads to multiple interpretations:

> The technician wanted to reduce the vibration of the fan at the exhaust as the exhaust ducting was cracking.

Does the word *as* mean "while" or does it mean "because"? A reader could easily interpret the word either way. In scientific writing, having the meaning teeter in two ways is unacceptable. In this example, the engineer wanted the meaning "because." For that reason, the engineer should choose the word *because,* which has only one meaning.

In other types of writing such as poetry, using the word *as* to mean "because" would be not only allowed but also encouraged. Because syllable count in poetry is important, opting for the one-syllable word *as* can be justified. However, as Lesson 2 discussed, professional readers see both one-syllable words and two-syllable words as short words [4]. For that reason, when you want the meaning of "because," you should select the word *because*:

> The technician wanted to reduce the vibration of the fan at the exhaust because the exhaust ducting was cracking.

## Consider the ordering of words, especially the word *only*

When scientists and engineers are not careful about the ordering of words and phrases, ambiguities can occur:

> The proposed schedule is discussed below for the next four years.

This sentence contains an ambiguity: Does the schedule extend for 4 years or will the discussion of the schedule take the reader 4 years to read? As you might expect, the writer intended the first meaning. Although readers upon reflection would arrive at the first meaning, they would have wasted time thinking about this tangential question. The source of this ambiguity is the positioning of the prepositional phrase "for the next four years." This detail about time occurs too late in the sentence. Revision gives—

> The proposed schedule for the next four years is discussed below.

Unlike most languages, the English language is flexible in terms of word order. For instance, from the perspectives of grammar and clarity, you may write any one of the following:

> We located the satellite.
> The satellite was located by us.
> The satellite we located.

Which order you choose would depend on the desired emphasis and the transition from the previous sentence.

In German, because precision is such an important part of the culture, such flexibility does not exist. In fact, the German language even has a specific order for modifiers: (1) details about time, (2) details about manner, and (3) details about place. Time, manner, and place—such an order avoids many ambiguities that arise in English. When confronted with the insertion of several details in a sentence, you would do well to remember the German sequence.

The improper placement of phrases, particularly introductory phrases, can also cause ambiguities.

> In low water temperatures and high toxicity levels of oil, the technician tested how well the microorganisms survived.

Let us hope that the technician conducting the tests survived as well. Revision with attention to clarity gives

> The technician tested how well the microorganisms survived in low water temperatures and high toxicity levels of oil.

One word in English probably causes more ambiguities because of its placement than any other. This word is *only*:

> *Only* I sighted the cheetah yesterday.
> I *only* sighted the cheetah yesterday.
> I sighted *only* the cheetah yesterday.

I sighted the *only* cheetah yesterday.
I sighted the cheetah *only* yesterday.

This example presents five different arrangements of this six-word sentence, and each sentence has a different meaning. The word *only* often causes problems because the word is sometimes an adjective (first and fourth sentences) and sometimes an adverb (second, third, and fifth sentences). Be careful about the placement of *only*. When you see it during a revision, a red flag should go up telling you to make sure that the word occurs in the proper position.

## Be selective with *it* and avoid the standalone *this*

According to Fowler's *A Dictionary of Modern English Usage*, which is a bible of sorts for the use of words in English, the reader should not have "even a momentary doubt" as to what a pronoun refers [5]. Many scientists and engineers, unfortunately, do not abide by this principle:

> Because the receiver presented the radiometer with a high-flux environment, it was mounted in a silver-plated stainless steel container.

What is mounted in the container? The receiver? The radiometer? The environment? The noun *environment* is the nearest possible reference to the pronoun *it*, but that reference makes no sense. The noun *receiver* receives the most emphasis in the sentence but three pages later in this report, the reader learns that the receiver stands more than 15 meters tall, making it much too large to fit into the container. In other words, the engineer had intended the pronoun *it* to refer to the noun *radiometer*, although this noun was neither the noun nearest to the pronoun nor the noun that received the most emphasis in the sentence. Given the number of possible references in this example, the engineer should have just repeated the noun *radiometer*.

> Because the receiver presented the radiometer with a high-flux environment, the radiometer was mounted in a silver-plated stainless steel container.

The way that many scientists and engineers treat the pronoun *it* is unsettling but the way that many scientists and engineers treat the word *this* is criminal:

> No peaks occur in the olefinic region. Therefore, no significant concentration of olefinic hydrocarbons exists in fresh oil. This places an upper limit on the concentration of olefins—no more than 0.01 percent.

What does the chemist want the word *this* to refer to? To the last noun of the previous sentence: *oil*? To the subject of the last sentence: *concentration*? To the idea of the previous sentence: that no significant concentration of olefinic hydrocarbons exists? Actually, the word *this* in this example refers to none of these. The chemist intended the word *this* to refer to the lack of peaks in the olefinic region.

Unlike *it*, which is a pronoun and nothing else, the word *this* is a special type of adjective, which journalists occasionally use as a pronoun to refer to the idea of the previous sentence. Unfortunately, many scientists use the standalone *this* much more often. Worse yet, many of those uses refer to different things: the last noun used, the subject of the previous sentence, the idea of the previous sentence, or something else. Instead of using *this* as a pronoun, clarify your writing by letting *this* do what it does best—point.

> The chromatogram has no peaks in the olefinic region. Therefore, no significant concentration of olefinic hydrocarbons exists in fresh oil. This chromatogram finding places an upper limit on the olefin concentration—no more than 0.01 percent.

While inserting the standalone *this* is relatively easy for the writer, interpreting the standalone *this* can be much work for the audience. Much as a tired basketball player will lean and grab hold of her or his shorts during a free throw, using the standalone *this* is a sign that the author has become tired. The result can cause confusion, as occurred in the following email:

> If you receive an e-mail titled "Win a Holiday," do *not* open it. The email will erase everything on your hard drive. Forward this out to as many people as you can. The "Win a Holiday" virus is a malicious and not many people know about it.

What did the email's author want the audience to forward? The pronoun placement indicates that the writer wanted the audience to forward the virus "to as many people as you can." However, logic dictates that the author wanted the audience to forward the warning, not the virus. Therefore, the author should clarify that meaning:

> If you receive an e-mail titled "Win a Holiday," do *not* open it. The e-mail will erase everything on your hard drive. Forward this warning out to as many people as you can. The "Win a Holiday" virus is malicious and not many people know about it.

Although the revision required the author to spend an additional word, the expenditure was worthwhile because the audience could now gather the intended meaning on the *first* reading.

## Insert commas after introductory phrases and clauses

A fourth common source of ambiguities arises from missing punctuation. As Bernstein writes, punctuation marks act as road signs in the writing.[6] These marks tell readers when to stop and when to slow down. Especially important for preventing ambiguities are commas. Commas act as yield signs that tell readers when to slow down so that they will see the sentence in a certain way.

Many rules exist for commas. While some rules are not mandatory, others are. In scientific writing, when a comma is needed to keep a sentence from being misread, the comma is mandatory. Consider an example in which someone did not follow this rule:

> After cooling the exhaust gases continue to expand until the density reaches that of free stream.

This sentence requires a comma after "cooling." Otherwise, readers do not know where the initial phrase stops and the main part of the sentence begins. Consider another example:

> With the lid off the reactor core was exposed, allowing radioactive isotopes to escape.

Here, the engineer needs a comma after "off."

When defending their decision not to include a comma after an introductory phrase or clause, some engineers and scientists refer to a mysterious rule about the number of introductory words before a comma can be used. No such rule exists. For instance, if you begin a sentence with the word *however* to mean "on the other hand," that word must be followed by a comma—no exceptions. Otherwise, the audience could assume that *however* has the meaning of "no matter how." The bottom line is that if you are in doubt about whether to insert a comma after an introductory phrase, then do so. After all, it is not incorrect to have a comma after an introductory phrase or clause, even when the comma is unnecessary.

In addition to the absence of commas after introductory phrases, a source of ambiguity involves missing commas in a series of three or more items. In such a series, the guideline for engineers and scientists in the United States is that commas should separate each term:

> The three elements were hydrogen, oxygen, and nitrogen.

Engineers and scientists in other parts of the world do not follow this guideline. Instead, their guideline is to drop the comma after "oxygen" unless not having the comma causes ambiguity. However, lists in science and engineering commonly arise in which not having a comma does cause an ambiguity:

> The fluid serves as a transmission medium for hydrodynamic energy in the torque converter, hydrostatic energy in servos and logic circuits and sliding friction energy in clutches.

In this sentence, no matter whether you work in Dallas or Dublin, you should place a comma after "circuits." Otherwise, your readers will waste time deciphering the meaning:

> The fluid serves as a transmission medium for hydrodynamic energy in the torque converter, hydrostatic energy in servos and logic circuits, and sliding friction energy in clutches.

Punctuating lists in scientific writing requires special attention, because lists in science and engineering can be complex. Consider the following sentence from a recent journal article:

> In our study, we examined neat methanol and ethanol and methanol and ethanol with 10 percent water.

A question arises: How many fuels did the chemist examine? Four? Three? Two? One? A good lawyer could make a case for any of the four answers. In this particular example, a table in a later section of the paper revealed that the chemist had examined four fuels. To rid the above example of the ambiguity, the chemist would have benefitted from a colon and a return to the United States guideline for punctuating items in a series:

> In our study, we examined four fuels: neat methanol, neat ethanol, methanol with 10 percent water, and ethanol with 10 percent water.

More important than which guideline you choose for punctuating a series of items is that you check to make sure that the audience can read the list only one way.

As stated, ambiguities are difficult to find when you first draft a document. Just after a drafting session, the sentences are no longer fresh. What you need is distance from the draft. A good night's sleep provides such distance. Also providing distance is a different look for the document—for instance, a journal paper format single-spaced in two columns, as opposed to a first draft double-spaced in one column. With an email that you have to draft and proofread in the same sitting, you might try proofreading a printout of the email. Another trick, which my wife uses, is to highlight the email with her cursor as she proofreads. The highlighting shades the background and gives the words a different appearance. For your most important documents such as an important proposal, you should try to find at least two conscientious readers. If an ambiguity exists, chances are that one of them will catch it.

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# Sustaining Energy

*Vigorous writing is concise. A sentence should have no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts [1].*

—William Strunk

You are reading an important paper in your field and suddenly find yourself thinking about what you need from the grocery store. You sit up and reread the previous two paragraphs. Not more than three paragraphs later, though, you wonder whether your black lab is in his doghouse or sleeping under the oak. You admonish yourself to focus.

More than likely in this scenario, you are not the problem. Instead, the blame likely lies with the lack of energy in the writing. Some engineers and scientists assume that because scientific writing should be precise and clear, it must be dull. That assumption is false. In fact, if scientific writing is to inform and to persuade effectively, the writing has to be lively. Otherwise, in longer documents, the audience will tire or even abandon reading. Put another way, the longer your document is, the more important that sustaining the writing's energy becomes.

Sustaining energy in your writing begins with selecting strong verbs and concrete nouns. Verbs and nouns receive the heaviest accents in sentences. When those words are weak, the writing drags. Sustaining energy also occurs through making the writing concise. When too many needless words infiltrate



M. Alley, *The Craft of Scientific Writing*,
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sentences, the energy level of the writing sinks, much as a boat does with too much weight.

## Select energetic verbs

Verbs provide energy in sentences. When your verbs are energetic, the writing moves. However, when your verbs are lifeless, readers can tire after just a few sentences:

> A new process for eliminating nitrogen oxides from diesel exhaust engines is presented. Flow tube experiments to test this process are discussed. The percentage decrease in nitrogen oxide emissions is revealed.

In this paragraph, no energy emanates from any of the three verbs: *is presented*, *are discussed*, and *is revealed*. The verbs flounder because of the following problems: (1) the verbs occur at the end, (2) the verbs are bloated, and (3) the verbs are passive.

**Avoid having verbs occur at the ends of sentences.** In English, you can think of a verb as the engine for the sentence. Put another way, the verb is what injects energy into the sentence. For that reason, placing the verb at the end, just before the period, makes no sense. Because the period acts like a stop sign for readers, placing the verb at the end is akin to hitting the accelerator of a car and then slamming on the brakes:

> In this study, the care given by a hospital and the medical outcomes of patients are compared. The effects of exogenous factors, such as the types of illnesses, are accounted for. Also, the opinions of both patients and physicians on the quality of health care are considered.

As with the paragraph that occurred earlier in this section, this writing exhausts readers. For each sentence, the main verb occurs at the end. For these verbs to inject energy into the writing, they have to occur earlier in the sentences.

Having the verb occur earlier in the first sentence is straightforward:

> This study compares the care given by a hospital and the medical outcomes of patients….

In this revision, the verb *compares* is the third word of the sentence. However, in the next two sentences, moving the verbs earlier is more challenging. One strategy, though, is to flip the sentence so that a participle of the verb occurs at the beginning and a form of the verb *to be* occurs in the middle. Following this strategy gives the following revision to the paragraph:

> This study compares the care given by a hospital and the medical outcomes of patients. Accounted for in the study are the effects of exogenous factors, such as the types of illnesses. Also considered are the opinions of both patients and physicians on the quality of health care.

In the second and third sentences of the revised paragraph, the participles *accounted* and *considered* occur at the beginning and forms of the verb *to be* (in both cases, *are*) occur in the middle. Although the verb *to be* is not itself an energetic verb, having that verb appear earlier in the sentence is more energetic than having the verb occur at the end.

**Tighten your verbs.** Verbs are like passes in basketball or soccer. In these sports, you want your passes to be crisp. However, many scientists and engineers sap strength from their verbs by burying them in nouns within weak verb phrases:

| Weak Verb Phrase | Strong Verb |
|---|---|
| made the arrangement for | arranged |
| made the decision | decided |
| made the measurement of | measured |
| performed the development of | developed |

Individually, these verb phrases bloat the writing by only two or three additional words. However, continually choosing these weak phrases results in an additional ten to twelve words in a paragraph and forty to fifty words in a section.

Sometimes, engineers and scientists bury strong verbs in other constructions:

| **Bloated Verb** | **Crisp Verb** |
|---|---|
| is beginning | begins |
| is dependent on | depends on |
| is following | follows |
| is shadowing | shadows |
| is a result from | results from |
| is used to detect | detects |

In each of these examples, the original verb phrase contains the verb *is*, which is form of the verb *to be*. The verb *is* acts as an equal sign, thereby serving a sentence that defines or equates:

> A positron is a positively charged electron produced in the beta decay of neutron-deficient nuclides.

However, if your sentence does more than define or equate, hiding the action in a noun leads to a lethargic sentence:

> The human immune system is responsible not only for the identification of foreign molecules, but also for actions leading to their immobilization, neutralization, and destruction.

Although this sentence contains much action and natural energy, the author relied on a *to be* verb and buried the action in long nouns. For lively writing, the verbs should contain the natural actions of the sentence:

> The human immune system not only identifies foreign molecules, but also immobilizes, neutralizes, and destroys those molecules.

In the revision, the action verbs *identifies, immobilizes, neutralizes*, and *destroys* have replaced the stagnant verb *is*. While the original sentence just sits, the revised sentence moves. The revision moves because the verbs reflect the natural energy of the idea.

An undesired use of the verb *to be* occurs in *there are* (or *there is*) constructions:

> In sub-Saharan Africa, there are more than 70 percent of the population who do not have access to electricity.

On first drafts, writing sentences that contain *there are* is natural to do—after all, the main goal in first drafts is to place your ideas onto paper. However, on your revisions, you should remove the words *there are* and tighten the sentence:

In sub-Saharan Africa, more than 70 percent of the population do not have access to electricity.

In this example, the revision consisted of simply removing three words: *there*, *are*, and *who*. In other cases, you will also have to insert a verb such as *exist* or *occur*.

**Select the natural voice.** Two main features distinguish the action of a verb: tense and voice. Tense refers to when the action occurs: past, present, or future. Voice, on the other hand, refers to the perspective for the action—in other words, who or what performed the action. While the timing of events in the work controls the tense of a verb (see "verb tense" in Appendix C), the author controls the voice of a verb. Voice strongly affects the energy of the writing. Verbs can be either ***active voice*** or ***passive voice***. In active voice, the subject performs the action, while in passive voice, the subject is acted upon:

Orbital debris struck the satellite. *(active)*
The satellite was struck by orbital debris. *(passive)*

Some scientists and engineers subscribe to the myth that all verbs should be passive voice. That is nonsense. In a document, although some verbs are naturally passive, making all the verbs passive slows the writing and reduces its efficiency:

The feedthrough was composed of a sapphire optical fiber, which was pressed against the pyrotechnic that was used to confine the charge. *(22 words)*

Eliminating the passive voice from this sentence tightens the writing, making it more energetic:

The feedthrough contained a sapphire optical fiber, which pressed against the pyrotechnic that contained the charge. *(16 words)*

Is all passive voice wrong? Certainly not. Although the active voice is stronger than the passive voice, occasions arise in which the passive voice is more natural:

On the second day of our wildebeest study, the herd migrated to the river. There, a calf wandered just a few yards from the herd and was attacked by painted dogs.

In this example, the first two verbs (*migrated* and *wandered*) are active, while the third verb (*was attacked*) is passive. Using the passive voice in the third case is appropriate, though, because the passive voice keeps the focus on the subject of the study (wildebeests), rather than shifting that focus to the painted dogs.

The key to choosing between an active or passive verb is to ask which form is more natural. Most often, an active verb is more natural. Unfortunately, some scientists and engineers continually choose passive verbs. Unnatural passive voice is lifeless. If energy has occurred in the work, unnatural passive voice saps that energy and leaves lifeless words on the page. Consider again the paragraph from the beginning of this section:

> A new process for eliminating nitrogen oxides from diesel exhaust engines is presented. Flow tube experiments to test this process are discussed. The percentage decrease in nitrogen oxide emissions is revealed.

This kind of writing could cure insomnia. The work is not boring but this writing is. One reason for this paragraph's dullness is that all the verbs are passive, and most passive voice is unnatural to our ears. Imagine listening to a baseball game in which the radio announcers speak in an unnatural passive voice:

> The ball is pitched by Gibson. The bat is swung by Clemente. The ball is hit by Clemente. The outfield is covered by Brock. The fence is climbed by Brock.

Boring, boring, boring. Radio announcers would not call a game that way—if they did, they would not have many listeners. A good announcer such as Harry Carey would have called the same play in a natural voice:

> Clemente digs in. Gibson comes set, delivers. Clemente swings. He drives the ball to deep left field. Brock races back, way back. He climbs the wall. That ball is gone.

Just as Carey strengthened his radio broadcasts using the active voice for most verbs, so too can you strengthen the summary of the journal article. However, to do so, you need to take the unnatural passive and make it active. To do so in scientific writing, two strategies exist, and both are controversial.

One strategy is to allow objects to act. Because many readers feel uncomfortable with inanimate objects acting in sentences, you have to be careful. Suppose in the first draft of a section about using an oscilloscope, you write

> The voltage was shown on the oscilloscope.

If you want to convert that unnatural passive voice to the active voice, which active verb you choose determines the reader's comfort level with the inanimate object's action.

| | |
|---|---|
| The oscilloscope displayed the voltage | *comfortable* |
| The oscilloscope measured the voltage | *marginal* |
| The oscilloscope calculated the voltage | *uncomfortable* |

For this sentence, selecting the verb *displayed* would be fine. No reviewers would challenge that use. However, selecting the verb *measured* would trigger a challenge from reviewers (namely, that the author measured the voltage using the oscilloscope), and choosing the verb *calculated* would evoke a rebuke from reviewers (namely, that the author endowed the oscilloscope with human qualities).

The lesson here is that as long as objects perform actions that they are endowed to do, the reader will not trip. In fact, such use of active voice often occurs in scientific documents:

> This paper *presents*....
> Figure 1 *shows*....
> The test setup *included*....
> Experiments *yielded* results....
> The results *indicate* that....

A second strategy for transforming passive voice to active voice is to use the first person (*I* or *we*). Some scientists and engineers hold the myth that the first person is forbidden in scientific writing. Granted, using the first person is not appropriate for many external reports arising from a company. The reason is that the question arises whether the first person (*we*) represents just the authors or the entire company.

However, for correspondence, research proposals, and research papers, using the first person, if done judiciously, is an excellent strategy. In his writings, Einstein judiciously used the first person. He was not only a great scientist but also a great writer. Pauling likewise used the first person, as did Curie, Darwin, Feynman, Goodall, Lyell, and Freud. As long as the emphasis remains on your work and not you, nothing is inherently wrong with using *I* or *we*.

Also, avoiding the first person at all costs leads to unnatural wording:

> In this paper, the authors assumed that all collisions were elastic.

The phrase "the authors assumed that" is silly. The reader can see the authors' names on the paper. Using the word *authors* instead of *we* suggests that the paper had a ghostwriter. Other unnatural phrases that arise from avoiding the first person include

> It was determined that…
> It was decided that…
> It was attributed to…

These phrases suggest that some force—the "It" force—did the "determining," "deciding," or "attributing." In cases where you make an assumption or decision, the first person is not only natural but expected. Consider an example in which the writers should have used the first person, but did not:

> In that an effort to identify a specific control circuit responsible for the failure of the gear box was unsuccessful, it was determined appropriate to resurvey the collector field for torque tube damage.

In this example, by avoiding the first person, the engineers shirked responsibility both for not finding what caused the gear box failure and for authorizing another survey of the field. Appropriate use of the first person would have been as follows:

> Because we could not locate the control circuit responsible for the gear box failure, we surveyed the collector field again for damage to the torque tubes.

When using the first person, how do you keep the emphasis on the work and not the person(s) doing the work?

First, you should reserve the use of the first person for those occasions in which your role in the work is important—for instance, when you assumed, measured, or decided. Second, you should avoid placing the first person (either *I* or *we*) as the beginning word of a sentence because that position receives heavy emphasis. Instead, have the first person follow an introductory word, phrase, or clause.

> To test this process, we performed experiments in flow tubes.

Although you use the first person judiciously and keep the emphasis on the work and not on yourself, you inevitably will run across managers or editors who will delete the first person from your drafts. In such cases, I have found the best thing to do is to disagree politely and to raise a rebuttal based on reason. However, if the manager or editor stands by the edit, you should accept the edit as a constraint for that document. You will find, though, that by continuing to use the first person judiciously on subsequent documents, you will wear down the manager's or editor's resentment of the first person. For one thing, the manager or editor will find it difficult to edit out appropriate use of the first person without fattening the sentences. Second, once the manager or editor becomes accustomed to hearing judicious use of the first person in a document, the manager or editor will realize the natural sound that the first person gives the writing.

Look yet again at the example that began this section:

> A new process for eliminating nitrogen oxides from diesel exhaust engines is presented. Flow tube experiments to test this process are discussed. The percentage decrease in nitrogen oxide emissions is revealed.

Strengthening the verbs of this summary with the strategies discussed yields the following revision:

> This paper presents a new process for eliminating nitrogen oxides from diesel exhaust engines. To test this process, we performed experiments in flow tubes. These experiments revealed a 99 percent decrease in nitrogen oxide emissions.

Unlike the original, which lies motionless on the page, the revision races with energy. What caused the difference were the choices in verbs. Strong verbs drive readers through documents.

## Rely on concrete nouns

While verbs infuse sentences with energy, nouns provide stepping stones to allow readers to stay on course. A noun is a word that represents a person, place, or thing. When your nouns are vague, the audience has difficulty in navigating the sentence:

> The existing nature of Mount St. Helens' volcanic ash spewage was handled through the applied use of computer modeling capabilities.

The nouns in this example—*nature*, *spewage*, *use*, and *capabilities*—are weak. Why? Because *nature*, *use*, and *capabilities* are abstract, they provide no helpful images or any other sensations to the readers. The noun *nature* may provide an image, such as a brook or a deer, but this image does not clarify the meaning of the sentence. The fourth noun, *spewage*, is not really a noun, but a verb ("to spew") cloaked as a noun. Taking a verb and twisting it into a noun is similar to taking a baseball pitcher and having that player bat in a critical situation. Granted, some pitchers such as Bob Gibson hit well, but most pitchers are easy outs. Just as a baseball manager relies on hitters to hit and pitchers to pitch, so should an author use nouns as nouns and verbs as verbs. Because the four nouns in the example are weak, the sentence suffers. Revision gives

> With supercomputers, we modeled how much ash spewed from Mount St. Helens.

This revision is much crisper and more direct. Notice that the nouns and pronoun in this revision—*supercomputers*, *we*, *ash*, and *Mount St. Helens*—provide stepping stones for readers to navigate the sentence.

Nouns that provide one of the five senses are ***concrete nouns***, and nouns that do not are ***abstract nouns***. In general, reducing the number of abstract nouns will strengthen your writing. Here is a short list of abstract nouns that often creep into scientific writing:

| | |
|---|---|
| ability | environment |
| approach | factor |
| capability | nature |
| concept | parameter |

The noun *environment* is particularly bothersome. When used to discuss an ecosystem, the word is appropriate. However, many scientists and engineers tag the word onto every other noun. These scientists and engineers do not talk about the "laboratory" anymore, but the "laboratory environment." In one paper, someone wrote about the "farm environment." What is wrong with the word *farm*? Adding the word *environment* in such a situation is superfluous and serves only to cloud the sentence's meaning.

Certainly, abstract nouns have an important role in scientific writing. However, for that to happen, the author should anchor the abstract noun with a concrete definition or example:

> This study considered three methods for detecting plastic explosives in airline baggage: ion mobility spectrometry, x-ray backscatter, and thermal neutron activation. To evaluate these three methods, we used four criteria: cost of the method, effectiveness of the method at identifying a plastic explosive, speed of the method at processing baggage, and ease of use for the method.

Because the writer grounded the abstract nouns *methods* and *criteria* with concrete examples, the writer made these abstract nouns concrete for the remainder of the document.

## Be concise

Being concise not only sustains the energy but also clarifies the meaning. Ridding sentences of pretentious diction such as *utilize* and *facilitate* leaves the verbs *use* and *make*, which are both more accessible and tighter. Likewise, choosing strong verbs also tightens your writing. For instance, when you replace needlessly passive verbs with active ones, you cut the needless phrases that accompany those verbs. This section discusses four ways to achieve conciseness in scientific writing: (1) eliminate redundancies, (2) eliminate writing zeroes, (3) reduce phrases to simplest forms, and (4) cut bureaucratic waste.

**Eliminate redundancies.** Redundancies are needless repetitions of words within a sentence. Redundancies either repeat the meaning of an earlier expression or else make points implicit in what has been stated. Adjectives are often redundant:

> The aluminum metal cathode became pitted during the glow discharge.

After the adjective *aluminum*, the word *metal* is redundant. Like adjectives, adverbs are often redundant. Below are common redundancies in scientific writing. The words in red can be deleted.

| | |
|---|---|
| already existing | introduced a new |
| alternative choices | mix together |
| at the present time | never before |
| basic fundamentals | none at all |
| completely eliminate | now at this time |
| continue to remain | period of time |
| currently being | private industry |
| currently underway | separate entities |
| empty space | start out |
| had done previously | still persists |

Many more redundancies exist besides the ones listed here. Because everyone writes redundancies in early drafts, you have to catch redundancies in your editing. An effective way is to read with the sole intention of cutting words.

**Eliminate writing zeroes**. A second way to become concise is to eliminate writing zeroes, which are empty phrases that provide no information to your readers.

> It is interesting to note that more than 90 incidents of satellite fragmentations have produced more than 36,000 kilograms of space debris.

The phrase "it is interesting to note that" is a zero. If the idea is not interesting, then the writer should not include it. However, if the idea is more interesting than other ideas, then the writer should find a stronger way to highlight it. One such strategy would be placing the tightened sentence at the beginning or end of a paragraph.

Sometimes, writing zeroes raise undesirable questions. Consider the following example:

> The requirements to be met for the detection system of plastic explosives include a detection rate of at least 95 percent and a false alarm rate of less than 5 percent.

The writing zero "to be met" is dangerously superfluous. It implies that requirements exist which will *not* be met.

Some common writing zeroes are

| | |
|---|---|
| as a matter of fact | it should be pointed out that |
| I might add that | the course of |
| it is noteworthy that | the fact that |
| it is significant that | the presence of |

Although these deletions appear small, they are important. Consider the following example:

> Vibration measurements made in the course of the rocket's flight test program were complicated by the presence of intense high-frequency excitation of the vehicle shell structure during the re-entry phase of the flight. (*33 words*)

Notice the writing zeroes "in the course of" and "the presence of." Notice also the redundancies "flight test (program)," "vehicle shell (structure)," and "re-entry (phase of the flight)" that were buried in noun phrases. Eliminating these writing zeroes and redundancies not only saves reading time but also invigorates the writing:

> Vibration measurements made during the missile's flight test were complicated by intense high-frequency excitation of the vehicle shell during re-entry. (*20 words*)

This revision is about two-thirds the length of the original. Even more important, the audience can comprehend this revision much more quickly. In the revision, the meaning becomes clear, much as a submarine takes shape when it surfaces the water.

**Reduce phrases to simplest forms**. A third way to be concise in your writing is to reduce phrases to their simplest forms. Just as you reduce mathematical equations to their simplest forms for easier comprehension, so too should you reduce phrases.

Some reductions can be made without hesitation. Consider the following examples:

| Original Wording | Reduction |
| --- | --- |
| at this point in time | now |
| at that point in time | then |
| due to the fact that | because |
| has the ability to | can |
| has the potential to | can |
| in the event that | if |
| in the vicinity of | near |
| owing to the fact that | because |

With many other reductions, you have to examine the wording in the context of the sentence. How do you find these reductions? To reduce equations to their simplest forms, you look for signals such as the same variable appearing on both sides of the equal sign. In the same way, to reduce sentences, you should look for signals such as too many adjectives, too many adverbs, nouns that contain verbs, and passive voice verbs.

One signal is the overuse of adjectives. An adjective is a word that modifies a noun. Often adjectives are needed because no noun exists that is specific enough to stand for the person, place, or thing being described. Nonetheless, you should challenge adjectives and weed out those that do not serve a purpose in your sentences.

> The objective of our work is to obtain experimental data that can be used in conjunction with a comprehensive chemical kinetics modeling study to generate a detailed understanding of the fundamental chemical processes that lead to engine knock. (*38 words*)

The adjectives *comprehensive*, *detailed*, and *fundamental* do not add anything here. Cutting the needless adjectives as well as the redundancies and writing zeroes, we obtain

> Our goal is to obtain experimental data that can be used with a chemical kinetics model to explain the chemical processes that lead to engine knock. (*26 words*)

Just as with previous examples, this revised sentence is not only tighter but the meaning of the sentence is clearer. Perhaps Twain said it best: "When you catch an adjective, kill it. No, I don't mean utterly, but kill most of them—then the rest will be valuable. They weaken when they are close together. They give strength when they are wide apart" [2].

Having too many adverbs also raises the flag that the writing could be tightened. An adverb is a word that modifies a verb, an adjective, or another adverb. Sometimes, adverbs earn their keep in sentences. All too often, though, adverbs are excess baggage. As Stephen King said, "The adverb is not your friend" [3]. One instance is using an adverb to modify a verb that does not need modifying. For example, the verb phrase "mix together" does not need the adverb *together*, because the verb *mix* does the job. After all, you do not mix things apart.

Another instance in which adverbs are unwanted occurs in modifying an adjective that is an absolute. For example, the adjective *unique* means unlike anything else. Given that, something is either unique or not unique—nothing exists in between. Therefore, the phrase "somewhat unique" makes no sense. Cut the adverb *somewhat*.

The adverb that causes the most problems is *very*, which is an intensifier. In a sense, the word *very* cripples the word that it modifies. For instance, if you describe a result as "very important" in the beginning of a document, you have essentially sapped the power from the word *important* for the rest of the document. From then on, any "important result" seems commonplace. Illogical and crippling uses of adverbs clutter sentences and reduce the writing's energy:

> The achievement of success of these advanced technologies depends very heavily on a rather detailed understanding of the complex processes that govern the velocities in the unburned gases prior to combustion. (*31 words*)

On its own, the verb *depends* is strong. However, coupling this verb with "very heavily" cripples its meaning. The same is true for the noun *understanding*, which the author coupled with "rather detailed." Cutting these needless adverbs and the baggage that they bring to the sentence not only shortens the writing but clarifies the meaning:

> The success of these advanced technologies depends on understanding what produces the velocities in the unburned gases prior to combustion. (*20 words*)

As the newspaper editor William Allen White said, "Substitute 'damn' every time you're inclined to write 'very'; your editor will delete it and the writing will be just as it should be" [4].

Nouns containing verbs are a third signal that the writing could be reduced. Turning verbs into nouns attracts needless adjectives and adverbs.

> The establishment of a well proven, well documented, rational methodology for making precise velocity measurements in the unburned gas has been realized and is being used extensively to aid in the development of numerical models, which in turn are used in the design of advanced piston engines. (*45 words*)

The nouns *establishment*, *measurement*, and *development* hide verbs that could reduce the fat hidden in this sentence. Much of this fat occurs in the string of modifiers before the noun *methodology*. If you pull out a five-dollar noun such as *methodology*, it should at least pay its own way through the sentence. However, this writer tossed the noun *methodology* onto a pile of unnecessary adjectives and adverbs. Revision gives

> Here, we have found a method to measure velocity in the unburned gas, and with this method, we are developing numerical models that will help design advanced piston engines. (*28 words*)

Finally, as mentioned earlier, needlessly passive verbs are another signal that your writing could be reduced to a simpler form. Much fat in scientific writing arises from unwanted passive voice:

> It was then concluded that a second complete solar mirror field corrosion survey should be conducted in July to determine whether the tenfold annual corrosion rate projection was valid and to allow determination as to whether subsequent corrective measures would be effective in retarding corrosion propagation. (*85 syllables*)

Revision gives

> To see whether the corrosion rate would increase tenfold as projected and to see whether stowing the mirrors in a vertical position would slow the rate, we decided to survey the solar mirror field a second time in July. (*61 syllables*)

Although this revision did not significantly reduce the number of words in the sentence, revision did significantly reduce the number of syllables. Syllable count affects reading efficiency, especially when you replace three- or four-syllable words with one- or two-syllable words [5]. In reducing the number of syllables of the last example, we have replaced vague and needlessly complex phrases such as "subsequent corrective measures" with precise and clear phrases such as "stowing the mirrors."

**Eliminate bureaucratic waste**. So far, this chapter has looked at being concise from the phrase and sentence levels. A broader perspective comes from examining needless paragraphs and sections. Much management writing is wasteful. In this kind of writing, abstract nouns such as *target*, *parameter*, and *development* fill the page without concrete examples to anchor the meanings. Before cutting through the deadwood at the phrase and sentence levels of management writing, you should consider who the audience is for the document and what the audience wants to learn from the document. That type of thinking often leads to deleting entire paragraphs and sections.

Consider the following preface written by the Department of Energy for the reports in one of its solar energy programs. The audience for the preface was varied: solar engineers, contract engineers, government officials, and the public.

> The research and development (R&D) described in this document was conducted within the U.S. Department of Energy's (DOE) Solar Thermal Technology Program. The goal of the Solar Thermal Technology Program is to advance the engineering and scientific understanding of solar thermal technology, and to establish the technology base from which private industry can develop solar thermal power production options for introduction into the competitive energy market.
>
> The Solar Thermal Technology Program is directing efforts to advance and improve promising system concepts through the research and development of solar thermal materials, components, and subsystems, and the testing and performance evaluation of subsystems and systems. These efforts are carried out through the technical direction of DOE and its network of national laboratories who work with private industry. Together they have established a comprehensive, goal-directed program to improve performance and provide technically proven options for eventual incorporation into the Nation's energy supply.
>
> To be successful in contributing to an adequate national energy supply at reasonable cost, solar thermal energy must eventually be economically competitive with a variety of energy sources. Components and system-level performance targets have been developed as quantitative program goals. The performance targets are used in planning research and development activities, measuring progress, assessing alternative technology options, and making optimal component developments. These targets will be pursued vigorously to insure a successful program.

In this preface [6], the Department of Energy did not anchor its nouns. For instance, why did the authors bother to mention the terms *targets* or *goals* in the third paragraph if the authors did not let the readers know what those targets and goals were? The readers who understood this preface were not the readers of the program's solar reports. The readers who understood this preface were the Department of Energy members who wrote the preface. In other words, the Department of Energy wrote this preface to itself. Revision with consideration of the audience gives the following:

> The research described in this report was conducted within the U.S. Department of Energy's Solar Thermal Technology Program. This program directs efforts to incorporate technically proven and economically competitive solar thermal options into our nation's energy supply. These efforts are carried out through a network of national laboratories that work with industry.

Although this revision is less than half the length of the original, it has more than twice the power. Fat writing is lethargic writing. Concise writing moves.

## References

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2. Mark Twain, letter to D. W. Bowser (20 Mar 1880).
3. Stephen King, *On Writing: A Memoir of the Craft* (New York: Scribner, 2000), p. 125.
4. William Allen White, relayed in column of Seattle newspaper (1935). Many people attribute this quotation to Mark Twain, but the following website makes a strong case for it being coined by White: http://quoteinvestigator.com/2012/08/29/substitute-damn/.
5. Robert F. Gunning, "The Fog Index after Twenty Years," *Journal of Business Communication*, vol. 6, no. 2 (1969), pp. 3–13.
6. Department of Energy, *Solar Thermal Technology Annual Evaluation Report* (Golden, CO: Solar Energy Research Institute, 1985), p. ii.

Lesson 5

# Connecting Your Ideas

*All of my graduate students learned to write with precision and clarity, but only a few wrote with seamless transitions between the ideas. You had the impression that for these few the writing came without effort, but of course it did not* [1].

—Karen Thole

Although your sentences are precise, clear, and energetic, your writing still might not succeed at the paragraph level. Another stylistic criterion for success at this level is that the ideas of the individual sentences connect. While each sentence conveys one idea, a paragraph conveys a group of linked ideas. Unfortunately, many paragraphs in scientific writing falter because the sentences are disconnected:

> Mount St. Helens erupted on May 18, 1980. A cloud of hot rock and gas surged northward from its collapsing slope. The cloud devastated more than 500 square kilometers of forests and lakes. The effects of Mount St. Helens were well documented with geophysical instruments. The origin of the eruption is not well understood. Volcanic explosions are driven by a rapid expansion of steam. Some scientists believe the steam comes from groundwater heated by magma. Other scientists believe the steam comes from water originally dissolved in the magma. Scientists have to understand the source of steam in volcanic eruptions. Scientists have to determine how much water the magma contains.

How long can you read this style of writing? Ten pages? Two pages? Most readers lose interest before the end of the paragraph, even though the paragraph discusses the Earth's most dramatic geophysical event of the past 100 years.


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_5

One reason that the paragraph falters is that the reader has to work hard to see the connections between some of the sentences. For example, the connection between sentence 2 and sentence 1 does not occur until the last three words of sentence 2:

1. Mount St. Helens erupted on May 18, 1980.
2. A cloud of hot rock and gas surged northward from its collapsing slope.

Once the audience figures out the connection to the first sentence, so many disconnected details have already passed that many in the audience have to reread the sentence. When audiences have to reread in this way, they often claim that the writing is "choppy" or "does not flow."

Although having weak connections between ideas is certainly a problem in this paragraph, an even larger problem is that the sentences lack variety. Stagnant sentence rhythms make for tiresome reading. Even readers deeply interested in the content have difficulty enduring more than a paragraph or two of this style. In addition, the longer a document is, the bigger this problem of not varying sentences becomes. As shown in Figure 5-1, one cause for the lack of sentence variety is that all the sentences open with a subject noun: "Mount St. Helens" "cloud," "effects," "origin," and so forth. Adding to the lack of variety of sentence openers is that all the sentences have a single main clause, as opposed to a compound main clause or

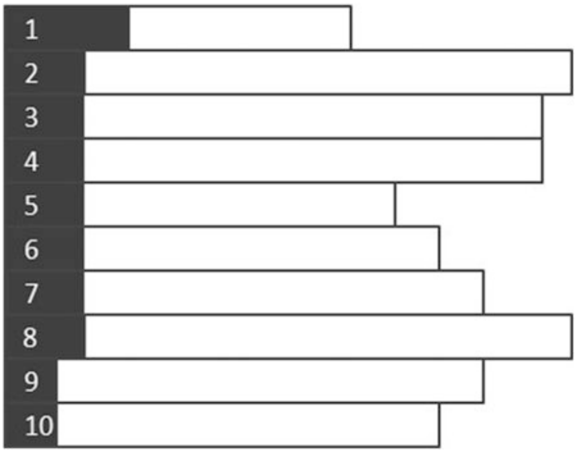


**Figure 5-1.** Depiction of where the subject (dark block) occurs in each sentence of the volcano paragraph. For energetic rhythms, this position should vary.

an added dependent clause. For that reason, each sentence has only one subject. Because the subject naturally receives a heavier beat than other words in the sentence and because this lone beat appears at the beginning of every sentence, a tiresome pattern develops.

Yet another source for the lack of sentence variety is that all the sentences have roughly the same length: 8–13 words. For that reason, the period, which is a stop sign for the reader, occurs at regular intervals. This pausing at regular intervals tires readers much as the repeated pendulum swings of a hypnotist's watch do.

## Begin each new sentence in a way that connects with the one before

As discussed, the chapter's opening example about Mount St. Helens suffered because of a lack of connections and because of a lack of sentence variety. Moreover, the lack of variety occurred in three aspects: sentence openers, sentence structures, and sentence lengths. At this point, you might find it daunting to address each of these issues. After all, you as an author have already expended much energy making the individual sentences precise, clear, and energetic. Nonetheless, you can address all of these problems with a single strategy: *Begin each new sentence in a way that connects the new sentence with the one before*.

In effect, this strategy, which Figure 5-2 depicts, focuses on the first challenge: connecting the ideas. Interestingly, when you connect your ideas at the beginning of a new sentence, you achieve sentence variety. How so? When you connect ideas in science, the types of connections will naturally change from details of *what* (or *who*) to details of *when*, *where*, *how*, and *why*. This change simply reflects the different ways that scientists and engineers analyze things. Likewise, a change in the type of connection (for example, changing from *what* to *why*) will usually call for a different sentence opener (for example, changing from a subject noun to a dependent clause). Finally, having different sentence openers leads to having different sentence structures and different sentence lengths.

**Figure 5-2.** Strategy of beginning each new sentence with a detail that best connects that new sentence to the sentence before. As reflected by the different shades and sizes, such variation will lead to an energetic variety of sentence structures and lengths.

The success of this strategy is evident in a revision of the first five sentences of the volcano paragraph:

> Mount St. Helens erupted on May 18, 1980. Its slope collapsing, the mountain emitted a cloud of hot rock and gas. Within minutes, the cloud devastated more than 500 square kilometers of forests and lakes. Although the effects of the eruption were well documented, the origin is not well understood.

As would be expected, because this revision focused on making the beginning of the new sentence connect with the previous sentence, the connections between sentences occurred earlier. For instance, consider the contrast between the connections of the first two sentences in the original and in the revision.

### Original

1. Mount St. Helens erupted on May 18, 1980.
2. A cloud of hot rock and gas surged northward from its collapsing slope.

### Revised

1. Mount St. Helens erupted on May 18, 1980.
2. Its slope collapsing, the mountain emitted a cloud of hot rock and gas.

While the connection between the first and second sentences of the original did not occur until the end of the second sentence, the same connection in the revision occurs at the beginning.

The focus on making connections at the beginning of sentences also led to variety in the types of connections—from the *what* (sentence 1) to the *how* (sentence 2), to the *when* (sentence 3), and to the *why* (sentence 4). What was the effect of these changes in type of connections on sentence variety? Although sentence length did not change appreciably, the change in structure for sentence 4 was noticeable. Because sentence 4 began with a dependent clause, this sentence's structure contained two subjects and two main verbs—one subject and verb for the dependent clause and another subject and verb for the sentence's independent clause. More striking, the sentence openers varied a great deal, from subject noun (sentence 1) to ***participial phrase*** (sentence 2), to prepositional phrase (sentence 3), and then to dependent clause (sentence 4). As shown in Figure 5-3, these changes in sentence variety led to a significant change in the sentence rhythm, as reflected by the positioning of the subjects of the sentences.

Making a strong connection at the sentence's beginning is an effective strategy not only to strengthen the connections between ideas but also to achieve sentence variety. However, this strategy hinges on a major assumption: that you can begin a new sentence in the way that best connects with the idea of the previous sentence.

To make such connections, you need two things. First, you should have an ample supply of short transitional words

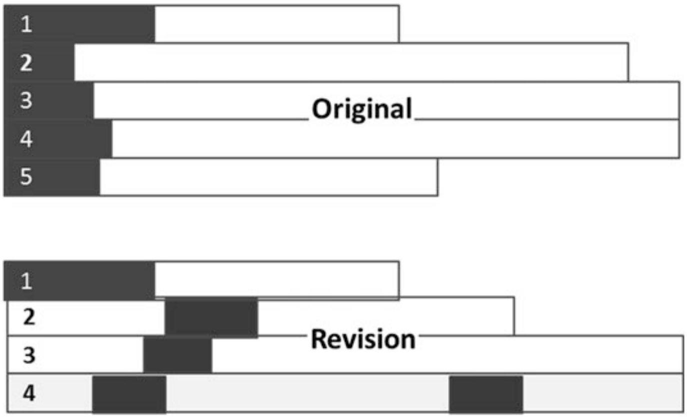


**Figure 5-3.** Comparison of one aspect of rhythm—the location of the subject—for the first five sentences of the original Mount St, Helens paragraph versus the subject locations in the revision. The different shadings for sentence 4 of the revision reflect the different sentence structure (two clauses: one dependent and one independent).

and phrases such as *also, for example*, and *however* to link ideas. The first subsection of this section provides an assortment of such connections. Second, you should have an array of sentence openers at your disposal to handle the connections of *what* (or *who*), *when, where, how,* and *why*. If you look at the sentence openers of professional writers, you will find much variety: typically, five types of openers used regularly in each section and another five or more openers sprinkled throughout. In contrast, if you look at the variety of sentence openers by less experienced authors, you will find only two or three openers used regularly and then only one or two more sprinkled throughout. In other words, while professional writers connect ideas in ten or more distinct ways, many engineers and scientists connect ideas in only four or five.

Discussed in this section are fifteen different types of sentence openers that are effective at connecting ideas in science and engineering. The first five are basic ingredients, much as a baker relies on flour and butter in each baked good. The next five are sophisticated openers, similar to a baker's use of oatmeal and chocolate chips to create favorite varieties. The remaining five are for special occasions, similar to a baker's use of nutmeg and ginger during holidays. Concluding the section is the integration of these sentence openers into the original volcano paragraph.

In this section, you will encounter several grammatical terms, all of which the Glossary defines. Although you might not have seen these terms since middle school, you should not be intimidated. For each sentence opener, the important takeaway is not the term itself, but the way to construct the opener. In other words, by the end of this section, you should be able to construct an opener such as "to understand the eruption," even though the term *infinitive phrase* might not come to mind.

**Linking Words and Phrases**. When used as sentence openers, many adverbs such as "also" and phrases such as "for example" make quick connections between the idea of the previous sentence and what the new sentence contains. In scientific writing, three important categories of such links occur:

(1) continuing the idea, (2) pausing to examine the idea in more detail, and (3) contrasting the idea. Because these linking adverbs and phrases occur at the beginnings of sentences, these words receive much emphasis. For that reason, repeating the same word or phrase as an opener in a paragraph or in some cases on the same page can distract readers. As shown in Table 5-1, you should have a variety of such linking words and phrases for each category: continuing, pausing, and contrasting. Certainly, additional adverbs and phrases for each category exist. What is important, though, is that you have an assortment of these words and phrases at your disposal so that you are not repeating the same ones too close together.

**Basic Sentence Openers**. Every scientific writer should own the following five sentence openers: subject noun, prepositional phrase, adverb, infinitive phrase, and dependent clause. Table 5-2 presents an example of each.

The subject noun opener is the most common type of sentence opener. This opener provides a *what* (or *who*) detail. When followed by the sentence's main verb, a subject noun opener is the most direct way to move the writing from point A to point B:

**Table 5-1.** Assortment of linking adverbs and phrases for scientific writing.

| Continuing | Pausing | Contrasting |
|---|---|---|
| Also, | In other words, | However, |
| In addition, | Put another way, | On the other hand, |
| Moreover, | In essence, | In contrast, |
| Furthermore, | In effect, | Conversely, |
| Therefore, | For example, | Still, |
| As a result, | For instance, | Nonetheless, |
| For that reason, | Likewise, | Otherwise, |
| Consequently, | Similarly, | Alternatively, |

**Table 5-2.** Basic sentence openers for scientific writing.

| Category | Example |
|---|---|
| Subject noun | Mount St. Helens erupted on May 8, 1980 |
| Prepositional phrase | Within minutes, the mountain emitted a cloud of hot rock and gas |
| Adverb | Recently, debate has arisen over the source of the steam |
| Infinitive phrase | To understand eruptions, scientists have to understand how much water the magma contains |
| Dependent clause | As the north side of the summit began to collapse, a huge explosion occurred |

> Magma intruded into the edifice of Mount St. Helens.

In scientific writing, the subject noun opener often occurs in the first sentence of a document or section. This opener also is used to state an important result: "A landslide ensued." However, as was shown in the original paragraph about the 1980 eruption of Mount St. Helens, relying on this opener for every sentence soon makes the reading tiresome. In addition, this opener often fails to connect with the previous idea.

A second common way to begin sentences is to use a prepositional phrase. Prepositions such as *before, during, and after* introduce phrases for *when* and prepositions such as *above, around, under*, and *below* introduce phrases for *where*:

> On March 16, 1980, the first sign of activity at Mount St. Helens occurred as a series of small earthquakes. *(when)*

> On the mountain's northern flank, a bulge appeared. *(where)*

If positioned properly, prepositional phrases can help a reader navigate through a paragraph or even a section. For example, consider a section in which the first paragraph begins "Before the eruption." If the next paragraph begins "During the eruption," the audience will expect a later paragraph to begin "After the eruption." Such an expectation, if fulfilled, is wonderful, because the author has conveyed the chronological strategy of the section with nothing more than two well-positioned prepositional phrases.

A third common way to begin sentences is with an adverb. Adverbs supply a number of different connections, including *how*:

> Unexpectedly, a magnitude 5.1 earthquake occurred. *(how)*

While many adverbs do end in *–ly*, the most important adverbs for scientific writers do not.

> Also, the volcano's northern bulge and summit slid away as a huge landslide.

Although the adverb *also* does not actually supply a connection for *what, when, where, how,* or *why*, this adverb as stated earlier signals the reader that the new sentence will continue with the idea of the previous sentence. Other similar adverbs, which Table 5-1 introduced, are *moreover* and *therefore*.

The infinitive phrase is a fourth sentence opener that every scientist and engineer should own. An infinitive is nothing more than a verb with the word *to* place before it. Building on that definition, an infinitive phrase consists of the infinitive and the words accompanying it. In scientific writing, an infinitive phrase is an important sentence opener because it answers the question *why*:

> To measure the bulge, we compared aerial photographs of the mountain from April 1980 with those back before the eruption activity. *(why)*

As shown in this example, beginning with an infinitive phrase is a deft way to incorporate the first person (*I* or *we*) into the writing. Why? What the infinitive phrase does in that sentence is to place the emphasis on the bulge measurement, as opposed to the subject (*we*). Remember: A detail at the beginning of a sentence receives more emphasis than does a detail in the sentence's middle. When Linus Pauling incorporated the first person into a sentence, he often began the sentence with an infinitive phrase.

Yet a fifth way to begin sentences is with a dependent clause. As you might remember from grade school, a clause is group of words that contains a subject and verb. An independent clause can stand alone as a sentence, but a dependent clause cannot. The first word of the dependent clause dictates the type of connection (primarily *when* or *why*) the clause makes:

> After the earthquake occurred, the volcano's northern side and bulge slid away as a huge landslide—in fact, the largest recorded debris landslide in history. *(when)*

> Because the mountain erupted so violently and unexpectedly, many people were unable to escape the blast. *(why)*

Because sentences with dependent clauses generally contain more than 20 words, beginning the sentence with the dependent clause lets the reader know early on that the sentence will be longer. Conversely, not doing so often stretches the patience of the reader:

> Most dwellings in this region of Mauritania do not have access to electricity, so these homes have no steady light source at night unless they choose to burn a gas lamp or candle.

Although the word *so* grammatically connects the first two clauses, the connection is unsophisticated. In essence, the audience has no clue that the sentence will have more than one clause until the reader reaches *so.* A more refined connection would provide an early clue about the sentence's length:

> Because most dwellings in this region of Mauritania do not have access to electricity, these homes have no steady light source at night unless they choose to burn a gas lamp or candle.

Do not be swayed by the myth that you cannot begin a sentence with *because. The Wall Street Journal, Scientific American,* and *National Geographic* contain many such sentences. Moreover, connecting clauses with just the word *so* reeks of grade school writing. Note that while a simple *so* connection for clauses is not sophisticated, a *so that* connection is. Such a sentence has a cause–effect structure, which is important in science and engineering.

Finally, because sentences with dependent clauses convey more complex ideas, a sentence containing a dependent clause is said to have a ***complex sentence structure***. Given that the ideas of these sentences are more complex, authors should intersperse ***simple sentence structures*** among complex sentence structures. In effect, the simple sentences place readers in a position to understand the more complex ideas that the complex sentence structures contain.

**Sophisticated Sentence Openers**. Some engineers and scientists worry that making their writing clear and concise will also make their writing appear simplistic. However, a sophisticated writing style is not achieved solely from having longer words and sentences. Another way to achieve such a style is to vary the arrangements of words in relatively short sentences. Through this type of sentence variety, your writing style can be clear, concise, *and* sophisticated. Such a style is the trademark of many great writers such as John Steinbeck, Annie Dillard, and Raymond Carver.

Table 5-3 presents five sentence openers that can help you achieve such a style: participial phrase as modifier, ***gerundial phrase***, dependent clause as subject, ***correlative conjunction***,

**Table 5-3.** Sophisticated sentence openers for scientific writing.

| Category | Example |
|---|---|
| Participial phrase as modifier | Its slope collapsing, the mountain emitted a cloud of hot rock and gas |
| Gerundial phrase | Calculating the amount of ash required many assumptions |
| Dependent clause as subject | Why this earthquake triggered the eruption remains a mystery. |
| Correlative conjunction | Not only was the eruption the most deadly in U.S. history, but it was also the most economically destructive |
| Comparative correlative | The greater the tumescence, the more likely will be an eruption |

and ***comparative correlative***. As with the dependent clause, each of these sentence openers dramatically varies the rhythm of the common subject noun opener. Because the variations caused by these openers are so dramatic, you do not want to use these spices too often. Still, occasionally using these openers will significantly raise the level of your writing.

One sophisticated opener is a participial phrase used as a modifier. A participle is a form of a verb with the ending *-ing* ("measuring") or the ending *–ed* ("measured"). Participial phrases often serve as modifiers for nouns:

> Continually monitored since its observation, the bulge on the mountain's north flank grew to about 140 meters.

Because this opener contains a verb form ("monitored"), the opener is a dramatic departure from the common subject–verb cadence. One concern about this opener is whether the subject noun that follows the phrase is in fact what the phrase modifies. A common mistake is to insert a different noun after the phrase:

> Rising 24,000 meters into the atmosphere in only 15 minutes, scientists estimated the height of the ash cloud.

The scientists did not rise "24,000 meters into the atmosphere." Rather, the ash plume did. Such a mistake is termed a ***misplaced modifier***. To correct this mistake, the sentence has to be rearranged:

> As estimated by scientists, the height of the ash plume rose 24,000 meters into the atmosphere in only 15 minutes.

Length is a second concern about participial phrases. A long participial phrase can frustrate readers because it takes so long to find out what the phrase modifies that the readers have forgotten what details the phrase contains.

> Originating at 500 meters beneath a bulge on the north face and attaining a velocity of 175 meters per second, the volcanic blast was captured by photographs.

This sentence does not efficiently communicate because the audience does not fully appreciate the details in the long participial phrase until after seeing what the subject is. For that reason, the sentence structure forces most readers to reread the sentence. When you use participial phrases as openers, keep them short.

A sentence opener closely related to the participial phrase is the gerundial phrase. While this grammatical term sounds highfalutin, the construction is relatively simple. A gerundial phrase is nothing more than a participial phrase that acts as a noun in the sentence:

> Calculating the amount of ash required many assumptions.

In this sentence, the verb phrase "calculating the amount of ash" is the subject. Note that coming up with such a verb phrase is not as difficult as it might first appear. Gerundial phrases often arise from challenging the standalone *this.* As an author, your first attempt at expressing the idea of the example above might have been as follows:

> This required many assumptions.

As stated in Lesson 3, to avoid ambiguity, you want to specify the reference of the standalone *this*. For that reason, your first revision might have read as follows:

> This calculation of the amount of ash required many assumptions.

From here, obtaining the gerundial phrase simply occurred from tightening the sentence:

> Calculating the amount of ash required many assumptions.

A third sophisticated opener is a dependent clause used as the subject. Certain dependent clauses can serve as the subjects of sentences. Generally, these special types of dependent clauses begin with *what*, *when*, *where*, *how*, and *why*:

> What actually occurred was a sudden blast that reduced the mountain's elevation by 400 meters.

Although not often used, this opener is excellent for the last sentences of paragraphs, especially when you want to throw the emphasis on a detail at the end of the sentence.

Yet a fourth sophisticated sentence opener is a correlating conjunction. Common examples are *not only…but (also)*, *both… and*, *either…or*, and *neither…nor*. When used as an opener, correlative conjunctions signal the reader that the sentence will have either two subjects or two independent clauses:

> Both the more than 10,000 earthquakes over the previous two months and the 450-foot bulging of the mountain's north flank indicated that an eruption was imminent. *(two subjects)*
>
> Not only did the eruption reduce St. Helens' height by 1300 feet, but the eruption also left a crater 1 to 2 miles wide and 0.5 miles deep. *(two independent clauses)*

When using correlating conjunctions, you should ensure that the wording following the first conjunction is parallel in structure with the wording following the second.

A final sophisticated opener is the comparative correlative. Not typically taught in schools, this opener has a long standing in scientific writing:

> The higher the concentration of sulfur dioxide gas emissions is, the higher is the likelihood of an eruption.

Although used sparingly, this opener is excellent for the last sentence of a paragraph, especially when the correlation is a major finding in your work. Historically, in engineering and science, authors often treat one or both of the verbs as being understood:

> The higher the concentration of sulfur dioxide gas emissions, the higher the likelihood of an eruption.

Having such an understood verb is similar to having an understood subject ("you") in a command ("Turn on the computer").

**Special Occasion Openers**. The sentence openers presented so far occur with regularity in scientific documents. This section presents five additional sentence openers that are for special occasions. Although each is accepted grammatically, each carries risks stylistically. Table 5-4 presents these five openers: question, ***appositive***, adjective phrase, ***introductory series***, and ***direct object***. As with the sophisticated openers, each of these sentence openers dramatically varies the rhythm of the common subject noun opener. However, each carries a risk, because the opener occurs so seldom in scientific writing.

One easy opener for special occasions is the question, which has an opposite rhythm of a subject noun followed by

**Table 5-4.** Special occasion sentence openers for scientific writing.

| Category | Example |
|---|---|
| Question | Is it groundwater heated by the magma or water originally dissolved in the magma itself? |
| Appositive | The fifth highest peak in Washington before the eruption, Mount St. Helens dropped 400 meters of elevation after the eruption occurred |
| Adjective phrase | Ominous and billowing, the volcanic cloud spread northward |
| Introductory series | Ice, snow, water, and earth—these materials formed the volcanic mudflows that slid for miles down the Toutle and Cowlitz Rivers |
| Direct object | The tumescence we measured with tiltmeters |

the verb. You might assume that questions are inappropriate for many scientific documents. However, questions can be effective at making transitions. Richard Feynman, for instance, inserted questions in many of his scientific papers. When should you use questions? Perhaps an easier issue to address is when you should not use a question. Questions at the beginnings of documents are risky. Because so many college freshman essays have begun with questions, starting any type of document with a question risks *cliché*. Also, ending a document with a question is a problem because such a question can frustrate readers. At the end of a document, readers expect closure. Unanswered questions do not provide closure. A question works best in the middle of a paragraph when the author has already introduced a number of details. The question then serves to orient the reader by having the reader look at those details from a certain perspective. Once you ask the question, though, you should answer it in that same paragraph. Otherwise, you will leave the audience hanging.

A second sentence opener for special occasions is the appositive. Although an appositive is nothing more than a second subject, it is a distinctly different way to include information that otherwise would have been included in a second short sentence:

> The costliest volcanic eruption in U.S. history, the Mount St. Helens eruption led to the destruction of 250 homes, 47 bridges, and almost 300 km of highway.

Because the subject occurs twice before the verb, the appositive significantly changes the rhythm.

A third opener, which is similar in rhythm to the appositive, is the adjective phrase:

> Ominous and billowing, the volcanic cloud spread northward.

Commonly used in *National Geographic*, this opener has too dramatic a sentence rhythm for some reviewers. Nonetheless, if the adjective phrase is short and the sentence appears in the middle of a paragraph (rather than the beginning), the opener can be effective.

Still a fourth opener for special occasions is the introductory series:

> A large-scale flow of magma that stretched 600 square kilometers, the emission of 15 million tons of sulfur dioxide, and the largest debris avalanche in history—these were but three of the effects of the eruption of Mount St. Helens.

Essentially, an introductory series that precedes an ***em-dash*** is the mirror image of a list that follows a colon. Because of emphasis or transition, having the list at the beginning of a sentence is sometimes advantageous.

A final opener for special occasions is the direct object:

> …required a measurement of the tumescence. This variable we measured using tiltmeters.

As with the infinitive phrase, this opener is effective for keeping the emphasis on the work rather than the people doing the work. In the above example, the sentence could be replaced by a dependent clause beginning with *which*: "…tumescence, which we measured using tiltmeters." Sometimes, though, such a clause makes the sentence too long. In these cases, a direct object opener is an alternative.

**Integration of Sentence Openers**. As stated, fluid writing arises by beginning each new sentence in a way that connects with the sentence before. Such a strategy leads to the following revision of this lesson's initial paragraph [2]:

> Mount St. Helens erupted on May 18, 1980. Its slope collapsing, the mountain emitted a cloud of hot rock and gas. Within minutes, the cloud devastated more than 500 square kilometers of forests and lakes. Although the effects of the eruption were well documented, the origin is not well understood. Volcanic explosions are driven by a rapid expansion of steam. Recently, debate has arisen over the source for the steam. Is it groundwater heated by the magma or water originally dissolved in the magma itself? To understand the source of steam in volcanic explosions, we have to determine how much water the magma contains.

Unlike the original, this paragraph is a pleasure to read. The ideas connect, and the rhythms vary in a satisfying way. While the focus on the revision was on the sentence openers, variety also occurred in the sentence lengths and structures. As mentioned, given that you have only so much time to spend making your writing fluid, a wise investment is to spend that time on the sentence openers. Also, although this revised paragraph happened to contain seven different sentence openers, you need not pursue that much variety in your own writing. While no magic formulas exist for the degree to which sentence openers vary, you should simply remember that failure to vary sentence openers stagnates the prose and exhausts the readers.

One efficient way to check on sentence variety occurs during the revision process. If you find yourself becoming tired while reading your own work, draw a line and take a break. However, when you return, check the sentence openers in the previous two or three paragraphs before that line. In my own revisions, I find more often than not that these breaks indicate where my own sentence openers have become stagnant. Varying those openers not only strengthens the links between the ideas but sustains energy in the writing.

## Integrate equations into paragraphs

Often in scientific writing, the most efficient way to convey a relationship is through a mathematical or chemical equation. Without equations, even a simple relationship can appear needlessly complex:

> The absorptance is calculated as one minus the correction factor times the measured reflectance.

Here, the engineer has made the readers work too hard. Standing alone, this sentence is a puzzle, but in the middle of a document, this sentence is a wall preventing the audience from understanding the work.

An equation would have communicated the relationship much more efficiently:

> The absorptance ($A$) is calculated by
>
> $$A = 1 - kR,$$
>
> where $k$ is the correction factor and $R$ is the measured reflectance.

Here, the author has followed the standard convention for incorporating equations into scientific writing. First, the author defined the dependent variable ($A$) in the text before presenting the equation. A second convention is that the equation, even with the white space around it, is a grammatical part of a sentence in the paragraph. In essence, the equation is a clause with a subject ($A$) and a verb (=). Third, the independent variables that are not yet defined in the text ($k$ and $R$, in this case) are defined after the equation. Put another way, an equation is not only part of the paragraph but grammatically connected to a sentence within the paragraph.

Although equations simplify relationships, they still make for difficult reading. Readers must stop and work through the meaning of each variable. Therefore, anytime you introduce equations into your writing, you should show why those equations are important. In other words, you should give readers incentives to push through the work of understanding your equations.

The reaction $O_2 + H \rightarrow O + OH$ is the single most important chemical reaction in combustion. This equation is responsible for the chain-branching of all flame oxidation processes.

In addition, because equations are difficult to read, you want to make them as clear as possible. One thing you should do is to define all the terms in your equations. Do not assume that all your readers will read $\pi$ as the gas phase reaction order or ∂ as the ratio of unburned to burned temperatures:

The burning rate ($\Omega$) of a homogeneous solid propellant is given by

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

where $\rho$, $c$, and $\lambda$ are the gas-to-solid ratios for density, heat capacity, and thermal diffusion; $\tau$ is the scaled ratio of the rate coefficient for the gas phase reaction (reaction order $n$) to that of surface pyrolysis (reaction order 0); $\gamma_s$ is the ratio of the heat of sublimation to the overall heat of reaction; $Le$ is the gas phase Lewis number; $\alpha$ is the fraction of the propellant that sublimes and burns in the gas phase; and $\sigma$ is the thermal capacity [3].

Besides stating the importance of equations and defining all variables, you should also clearly state the assumptions of your equations. Readers have to know when your equations apply and when they do not:

The Townsend criterion for the electrical breakdown of a gas is given by

$$\frac{\omega}{\alpha}\left(e^{\alpha d} - 1\right) = 1,$$

where $\alpha$ is the primary Townsend ionization coefficient, $\omega$ is the secondary Townsend ionization coefficient, and $d$ is the distance between the electrodes. The criterion for breakdown is actually a physical interpretation of conditions in the gas rather than a mathematical equation because Townsend derived his theory for a steady-state case that had no provisions for transient events such as breakdown.

Without the caution in the last sentence, someone could misunderstand Townsend's criterion.

When presenting equations, you should also consider using examples to give readers a feel for the numbers involved:

> In the first stage (Stage I) of an electron avalanche, diffusion processes determine the avalanche's radial dimensions. The avalanche radius $r_d$ is given by
>
> $$r_d = (6Dt)^{1/2}$$
>
> where $D$ is the electron diffusion coefficient and $t$ is the time. In the regime of interest (where voltages are greater than 20% of self-breakdown), the time of development is so short that little expansion occurs. For the case of nitrogen at atmospheric pressure, $D \approx 860\ \mathrm{cm}^2/\mathrm{s}$, $t \approx 10^{-8}$ s, and $r_d \approx 7.2 \times 10^{-3}$ cm [4].

Although you might have shown an equation's importance, identified its symbols and assumptions, and given examples, you still may not have done enough. For clear writing, you should convey the physical meaning of the equation. As the physicist Paul Dirac said, "I understand what an equation means when I can predict the properties of its solution without actually solving it" [5]. Such is the type of understanding you want to give your readers:

> In 1924, Louis De Broglie made an astute hypothesis. He proposed that because radiation sometimes acted as particles, matter should sometimes act as waves. De Broglie did not base his hypothesis on experimental evidence; instead, he relied on intuition. He believed that the universe is symmetric. Using Einstein's energy relation as well as the relativistic equation relating energy and momentum, De Broglie derived an equation for the wavelength of matter, $\lambda_m$:
>
> $$\lambda_m = h/p_m.$$
>
> In this equation, $h$ is the Planck's constant and $p_m$ is the matter's momentum. In 1927, Davisson and Germer experimentally verified De Broglie's hypothesis.

This discussion could have introduced De Broglie's equation with a detailed mathematical derivation. Instead, the discussion presented De Broglie's argument for symmetry. A rigorous mathematical derivation is not always the best way to communicate an equation.

## Connect illustrations with the text

While an equation is grammatically part of a sentence, an illustration grammatically stands apart not only at the sentence level but also at the paragraph level. In other words, an illustration is not a part of a paragraph. That said, you should still connect illustrations to the text. That connection occurs first through a formal introduction by name: Figure 5-1, Table 5-1, and so forth. That connection also occurs through an explanation of the illustration within the text.

In essence, to connect illustrations with the text, you have to smooth the transition between what you write and what you show. The most important way to smooth this transition is to match the information in your text with what is in your illustration. You would be surprised at how often scientists and engineers will say one thing in their text and then present a figure or table that shows something quite different.

> The testing hardware of the rocket shown in Figure 5-4 has five main components: camera, digitizer, computer, I/O interface, and mechanical interface. Commands are generated by the computer and then passed through the I/O interface to the mechanical interface where the keyboard of the ICU is operated. The display of the ICU is read with a television camera and then digitized. This information is then manipulated by the computer to direct the next command to the I/O interface.

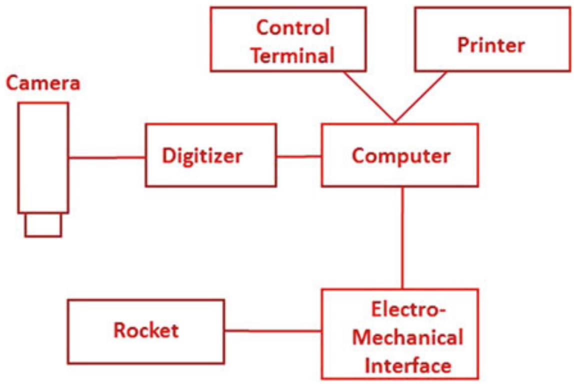


**Figure 5-4.** Testing hardware of rocket. This illustration does not agree with the accompanying text.

Figure 5-4 shows many weaknesses. For one thing, the system has seven parts—not five as stated in the text. Two of the parts (the printer and control terminal) are given names different from what is in the text ("I/O interface"). What is worse, the engineer depicted the rocket in the same manner as the testing system so that the reader cannot quickly distinguish the testing system from what is being tested. In other words, the rocket should be set apart in some way from the five main parts of the testing system. Finally, although this illustration is a diagram, you do not gain a sense of flow through the system. The engineer did not even aim the camera at the rocket.

Consider the following revision with attention to our goals for language and illustration:

> Our system for testing the safety devices of the rocket consists of four main parts: computer, electromechanical interface to the rocket, camera, and digitizer.In this system, shown in Figure 5-5, the computer generates test commands to the missile through the electromechanical interface. The test results are read with a television camera and then digitized. The computer receives the information from the digitizer and then directs the next test command.

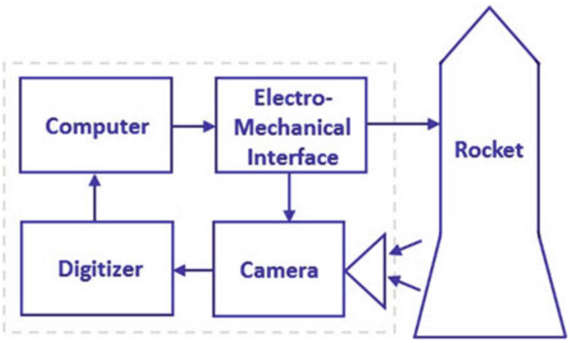


**Figure 5-5.** System for testing the safety devices of rocket.
This illustration does agree with the accompanying text.

Integrating illustrations with the text also means placing illustrations so that they closely follow their text references. Some engineers and scientists do not consider their audience when laying out illustrations in the text. Rather, these authors just place their illustrations at the end of a long document or fit them in wherever white space exists. Although this method may make things easy for the writer, it causes difficulties for the readers. Readers have a difficult enough time understanding the work without having to wander through the document to find a particular figure or table. Particularly troublesome is to place an illustration before its introduction in the text. Readers of scientific documents are not like readers of novels. They often do not read every section in its original order. Even if they do read the sections in order, readers often skim through certain sections. Therefore, an interesting figure that appears before its introduction in the text often causes readers to read backward, in vain, looking for its introduction.

Ideally, you would like to have each illustration fall just below the paragraph that introduces it. Unfortunately, page breaks often make this arrangement impossible. The next best arrangement then is to have each illustration to follow as closely as possible the paragraph that introduces it. This way, readers can quickly compare the text and illustration, and those readers who start with the illustrations and read backward will not have far to go.

On this note, when you introduce an illustration with wording such as "as shown in Table 5-1," do not include pointers such as "below" or "on the next page." Including such pointers is a rookie mistake by an author. Documents go through several revisions and including such pointers forces you, your coauthors, or your editors to make unnecessary changes. Because a scientific reader knows that the illustration will appear in the next available spot, these pointers and the accompanying editing changes are both unneeded and undesired. One exception here is when you refer back to an illustration that you have already introduced, explained, and shown. In such a case, rather than use a pointer, you simply clue the audience to the location of the illustration by using the past verb tense: "… as was shown in Figure 5-5."

Finally, do not think, as many scientists and engineers do, that your illustrations have to fill the entire image area of the page. Although you should make illustrations large enough to clarify details, you should also include a reasonable white space border. Where text borders white space is where you achieve emphasis.

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Lesson 6

# Beginning with the Familiar

*The whole of science is nothing more than a refinement of everyday thinking* [1].

—Albert Einstein

Given the inherent complexity of most scientific documents, the beginning has the steep challenge of orienting the audience. To do so, an effective strategy is to begin with what is familiar to the audience. Consider, for example, the strong opening paragraph of an article by Cliff Frohlich on deep earthquakes [2]:

> In most earthquakes, the earth's crust cracks like porcelain. Stress builds until a fracture forms at a depth of few kilometers and slip relieves the stress. Some earthquakes, however, take place where the earth cannot fracture. Such earthquakes, called deep earthquakes, occur hundreds of kilometers in the earth's mantle. At this depth, high pressure is thought to prevent the rock from cracking, even though stresses might be high enough to deform the rock like putty.

Although the focus of the article is on deep earthquakes, Frohlich began with a description of surface earthquakes. Why? Here, Frohlich wanted to orient his audience by beginning with what was familiar (surface earthquakes) before introducing



M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_6

what was new (deep earthquakes). Put another way, Frohlich wrote this section from his audience's perspective, not his.

In the first sentences, the best authors in science use this strategy of beginning with the familiar. In addition, the best authors use mapping sentences to prepare readers for what is ahead. Moreover, the best authors show sensitivity to what the readers know by defining new terms and by relating new concepts to what is familiar. Finally, the best authors carry this sensitivity into their illustrations.

## Select a first sentence that not only orients, but also takes a significant step

Both fiction writers and nonfiction writers sweat first sentences. What precisely makes for a strong first sentence in fiction is difficult to define. What can be said, though, is that a strong first sentence in fiction serves the story. For instance, many first sentences, such as this one for "A Good Man Is Hard to Find" by Flannery O'Connor, create tension:

> The grandmother didn't want to go to Florida [3].

Others, such as this one for "A Rose for Emily" by William Faulkner, set a stage:

> When Miss Emily Grierson died, our whole town went to her funeral: the men through a sort of respectful affection for a fallen monument, the women mostly out of curiosity to see the inside of her home, which no one save an old manservant—a combined gardener and cook—had seen in at least ten years [4].

With nonfiction, perhaps the most important attribute of a first sentence is that it makes the audience want to read the second. Consider, for example, the opening to *Into Thin Air* by Jon Krakauer:

> Straddling the top of the world, one foot in China and the other in Nepal, I cleared the ice from my oxygen mask, hunched a shoulder against the wind, and stared absently down at the vastness of Tibet [5].

In scientific writing, the stylistic variety afforded to sentences is not as broad as it is in fiction or journalism. Still, first sentences of documents and sections in scientific writing deserve special attention. One reason is that a first sentence receives much emphasis. Where text borders white space is where you achieve emphasis. For that reason, the first sentence should deliver valuable content to the audience. Moreover, because the title or section heading may not have fully clarified the scope, the first sentence should orient.

Given these two goals, how do you write the first sentence of a document or section? When the audience is familiar with the subject of the document or section, an efficient strategy is simply to incorporate the document's title or section heading into the first sentence of the document or section:

> ***Combatting Malaria with Mosquito Netting.*** This section introduces a new type of mosquito bed netting, coated with insect repellent, to reduce the spread of malaria among African children.

In this case, the author assumed that her audience was already familiar with the problem of malaria and how mosquitoes contribute to this problem [6]. For that reason, she used the first sentence to confirm the focus of the section. Although the sentence delivered additional details from what the section heading conveyed, those added details were ones that the audience could readily comprehend.

When the audience is not already familiar with the subject of the document or section, you should begin in a different way. Here, the most common strategy is to begin with background information that prepares the audience for that subject:

> ***Design of Downhole Steam Generator.*** More than half of the oil in a reservoir is too viscous to pump out with conventional methods. By heating these oils with steam and decreasing their viscosity, we can recover billions of gallons. For oils below 800 meters, though, the steam produced on the surface loses too much energy in transit to heat the oil. One way to overcome this problem is to use a downhole steam generator that applies hot steam directly.

In this example, because the audience was unfamiliar with the term "downhole steam generator," the writer chose to begin with details that made the audience more comfortable with this term. The background information for this strategy met two important criteria. First, the background information engaged the audience, because recovering billions of gallons of oil was inherently interesting to the audience. Second, the background information moved efficiently to the subject of the section. If your background is long winded, your reader might well forget the subject and wonder where the discussion is headed.

So far, this lesson has shown two possible strategies to follow. Are there strategies that you should avoid? Yes. One such strategy is the empty beginning. Because the first sentence of a section receives heavy emphasis, you want to say something in the first sentence that starts the readers on their journey up your mountain of work. Unfortunately, many authors waste the first sentence:

> The cooling of turbine blades in jet engines is important. This paper focuses on a cooling scheme that uses small internal channels to cool the inner portions of blades….

In this first sentence, nothing occurs. For those readers who already knew the importance of turbine blade cooling in jet engines, nothing was added. In contrast, for those who did not know this importance, the first sentence provided no argument to persuade them that the assertion was true. A better opening would have been as follows:

> The cooling of turbine blades in jet engines is important because the combustion gases that flow over the blades are more than 500 °C hotter than the blades' melting temperature [7]. This paper focuses on a cooling scheme that uses small internal channels to cool the inner portions of blades….

This first sentence advanced the paper by showing, rather than just telling, the readers that the work is important. The detail about the 500 °C provides evidence for the assertion, and the reference listing provides grounding for the evidence [8].

For a journal article in which space is restricted, such a single-sentence argument is often appropriate. In a report or thesis, though, because the author has more space to make this argument, the author should consider providing more evidence:

> The cooling of blades in gas turbine engines is important because the combustion gases that flow over the blades are more than 500 °C hotter than the blades' melting temperature [7]. In addition, these blades are expensive, often costing more than $25,000 for the replacement of each blade. Moreover, cooling can make a significant difference in a blade's life. For instance, reducing the temperature on a gas turbine blade by just 25 °C doubles the blade's life. This report focuses on a cooling scheme that uses small internal channels to cool the inner portions of blades….

Another type of beginning to avoid in scientific writing is *in medias res* (in the middle of things), which fiction writers often use. For instance, in Flannery O'Connor's "A Good Man Is Hard to Find," the story opens with a tense scene in which a family is on a long vacation drive. While such a beginning can work in fiction writing, it is not appropriate in scientific writing:

> ***Experiment.*** The specimens were thin-walled tubes of 304 stainless steel….

In this beginning, the engineer began with a detail (description of the specimens) that was too specific for the audience. Instead, the engineer needed to step back and give a bigger picture of the experiment before introducing the specimens.

A third type of beginning to avoid in scientific writing is the Genesis beginning. While the *in medias res* beginning opens with details that are too specific, the Genesis beginning opens with details that are much too general:

> Man has since the beginning of time attempted to acquire a greater and greater control over his environment. Gaining control over a situation serves not only a survival-related need, but also a psychological need. Man's need for better control of his environment has increased greatly during and following any time of major conflict, such as World War II. This need and desire for control is evident in all technological settings, including the welding field.

By conjuring images of prehistoric man and the Second World War, the engineer has created expectations that a document on welding, no matter how well written, just cannot deliver.

## Map sections in which readers could become lost

When you choose a strategy in scientific writing, you envision a strategy that is logical to follow. In your vision of the strategy, you see mileposts. Perhaps the mileposts form a sequence of steps, such as the stages of combustion, or perhaps the sections are parallel parts and sum to a whole (the three parts of a comet—head, coma, and tail). Mapping the section simply presents those mileposts to the audience. Consider the following first paragraph of a section:

> **Dangers of Breathing Compressed Air**
> Recreational scuba divers breathe compressed air at depths down to 190 feet. Breathing compressed air at these great depths and even at more moderate depths poses many dangers for scuba divers. The three most important dangers are nitrogen narcosis, decompression sickness, and arterial gas embolism.

This first paragraph in the section was followed by three additional paragraphs—one paragraph discussing nitrogen narcosis, the next discussing decompression sickness, and the third discussing arterial gas embolism [9]. The mapping at the beginning of the section prepared the reader for what was up ahead. More discussion of mapping occurs in Lesson 7.

## If you cannot avoid an unfamiliar term, then define it

For your writing to be informative, you have to use terms that your audience understands. When you have an audience outside your area of expertise, it is often difficult to find familiar wording. Why? Scientists and engineers work on particular crooks of particular ridges of particular mountains, and each mountain has its own special set of terms. These terms may be words or abbreviations:

| | | |
|---|---|---|
| plasma physics: | glow discharge | MHD |
| hemodynamics: | immunodeficiency | B cells |
| spectroscopy: | gas chromatography | GC/MS |

In scientific writing, the author (not the reader) bears the responsibility of bridging the language gap to the audience. The best authors in science have a sensitivity to what the audience knows and does not know. If your terms are not familiar, then you should either avoid them or define them. Likewise, if you introduce an unfamiliar concept to your audience, then you should find a way, such as an example or analogy, to explain that concept.

**Avoiding Unfamiliar Terms.** One of the simplest, yet most overlooked, ways to handle unfamiliar terms is to avoid them. This advice is especially pertinent when the unfamiliar term is ***jargon***, which is a vocabulary particular to a place of work. Jargon may be either abbreviation or slang. Do not assume that jargon is inherently bad. For communication within a place of work, jargon can concisely identify experiments and buildings. For instance, if you worked at the Pulsed Power Facility, when you write internal emails and reports, you might use the facility's jargon:

| | |
|---|---|
| PPF | Pulsed Power Facility |
| Jarva | a neodymium-glass laser in the facility |

For readers who work at the facility, this jargon poses no problem. However, when you write a journal article or an external report, this jargon alienates readers. In handling a piece of jargon, such as "Jarva," you can simply avoid the term. In the document, you would just use the "neodymium-glass laser" the first time, and the "laser" thereafter. For readers outside the facility, what difference does it make if your laser is named "Jarva" or "Olivia"?

The Department of Defense has become a master at creating jargon. In fact, the Department publishes a huge book each year that defines its current jargon. In the book are definitions for "Jolly Green Giant" (military transport helicopter), "Pony Express" (radar optics intelligence), and "Jack Frost" (winter military exercise). Some jargons have multiple meanings. For instance, the abbreviation ABC stands for one of the following: (1) American, British, and Canadian; (2) Argentina, Brazil, and Chile (the ABC countries); (3) atomic, biological, and chemical; or (4) advanced blade concept.

As a scientist or engineer, you want to use jargon only when it makes the reading more efficient for your readers. Many scientists and engineers, unfortunately, go out of their way to include every piece of jargon in their work, even when they are writing to readers outside their institution:

> For the first year, the links with SDPC and the HAC were not connected, and all required OCS input data were artificially loaded. Thus, CATCH22 and MERWIN were not available.

This paragraph reads like a cryptogram. Whenever precision allows, you should use common words, not unfamiliar jargon:

> Because some links in the computer system were not connected the first year, we could not run all the software codes.

Jargon not only alienates; it often misleads:

> The 17 percent efficiency of the water-to-steam system was a showstopper.

Someone not familiar with the word "showstopper" might interpret 17 percent as a favorable efficiency, so favorable that the show was interrupted by applause. In this sentence, however, the engineer meant just the opposite: The efficiency was so poor that the system was disregarded and the project was canceled.

**Defining Unfamiliar Terms.** When you cannot write around unfamiliar terms, then you should define them. Notice that unfamiliar terms include both usual words, such as "bremsstrahlung," that are particular to an area of work, and common words, such as "receiver," that can have unusual meanings in a particular area of work.

What is the best way to define a term? If a definition is short, you can include it within the sentence:

> In a central receiver system, a field of sun-tracking mirrors, or *heliostats,* focuses light onto a solar-paneled boiler, or *receiver,* mounted on top of a tall tower.

When the definition is complex or unusual, you should expand your definition to a full sentence.

> *Bremsstrahlung* is the radiation emitted by a charged particle that is accelerated in the Coulomb force field of a nucleus.

As shown in Figure 6-1, a formal definition of a noun begins with a noun that identifies the class to which the term belonged ("radiation" in the example above). That class of terms is then followed by enough information to separate that term from other terms in the class (in the example above, "emitted by a charged particle that is accelerated in the Coulomb force field of a nucleus"). Consider another example:

> *Retina* is light-sensitive tissue that is found at the back of the eye and that converts light impulses into nerve impulses.

Here, the noun phrase "light-sensitive tissue" establishes the class to which the term "retina" belongs, and the additional information separates retina from other types of light-sensitive tissues.

In general, to define an abbreviation, you place the abbreviation in parentheses after the first full expression of the term in the document:

> In a central receiver system (CRS), a field of solar mirrors focuses sunlight onto a central boiler or receiver. An example of a CRS is the Solar One Power Plant located near Barstow, California. Another example of a CRS is…

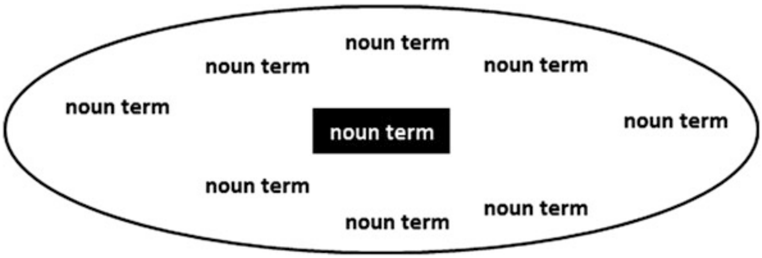


**Figure 6-1.** Form of a formal definition for a noun term. The ellipse encompasses the class of terms to which the defined term belongs and the shaded portion represents the additional information given to the term to separate it from the other terms in the class.

However, if the abbreviation occurs only a couple of times in the document, then you should simply avoid the abbreviation and write out the expression. For instance, if a document uses the abbreviation "CRS" only one or two times, you should not bother to include it. Instead, use "central receiver system." If, however, the abbreviation occurs several times, then you should define the abbreviation.

In regard to defining an abbreviation the first time that the term appears, an important exception exists. If a term appears only once or perhaps twice in the beginning of a long document, but several times in a later section, you would make things easier on your audience if you used the full expression in the earlier references and waited to define the abbreviation in the later section when you would use the abbreviation several times. Too often, an author defines an abbreviation on one page and then does not use that abbreviation until several pages later. How does this author expect the readers to remember an abbreviation's definition from several pages before? In such a case, what happens is that the reader forgets the definition and then has to scan back through the document looking for the abbreviation's definition—an exercise that does not make for efficient reading. One strategy for overcoming this situation is to include a glossary of key terms. This strategy is discussed in Lesson 8.

Finally, some abbreviations such as DNA, TNT, or AIDS are more commonly known than the terms they abbreviate. In such a situation, you should define the abbreviation somewhere in the document for completeness' sake, but treat the abbreviation as the familiar term in titles, summaries, and the main text.

**Anchoring Unfamiliar Concepts.** Two of the best tools for explaining unfamiliar concepts are examples and analogies. Scientists and engineers know the value of examples—the favorite mathematical textbooks were the ones with the most example problems. In your writing, you have many occasions to use examples. For instance, whenever you make general statements, you should anchor these statements with examples. Do not leave your readers clutching to generalities:

> Since the design of the Solar One Power Plant, significant advances have occurred in solar energy technology.

Unless anchored with an example, this statement will soon be forgotten because it relies on the general phrase "significant advances." You need a specific example that readers will remember:

> Since the design of the Solar One Power Plant, significant advances have occurred in solar energy technology. For example, experimental tests have shown that using molten salt, rather than water, as the heat transfer fluid could increase overall system efficiency from 17 percent to 25 percent.

Scientists and engineers often miss opportunities to enrich their writing with examples. Suppose, for example, that you had to justify the importance of supercomputers to a nontechnical audience. Many scientists and engineers would just state the amount of storage or the number of arithmetic operations per second. William Wilson, a computer scientist at Sandia National Laboratories, took a more thoughtful approach. In a proposal to the Department of Defense, he created an example to show how powerful supercomputers are:

> By the late Middle Ages, cities throughout Europe were building Gothic cathedrals. In this effort, citizens dedicated their entire lives to the construction of a single cathedral, often in competition with other cities for the highest or widest building. The only way, however, that architects could test a new design was to build a cathedral, a process that took over forty years. Unfortunately, many cathedrals caved in during or after construction because the designers had no way other than trial and error to test their designs. What took forty years to test in the Middle Ages could have been done in minutes on a supercomputer.

Wilson then backed up this example with a figure showing a supercomputer design of a cathedral with a height of 32 meters that proved successful [10]. Next to this design was a supercomputer design of a cathedral with a height of 41 meters that failed. After the proposal was published and distributed, Wilson flew to Washington to give a follow-up presentation.

Every proposal reviewer whom Wilson met remarked about the cathedral example. Examples are often what people remember.

In addition to examples, analogies are valuable at conveying complex ideas or numbers. Analogies compare obscure thoughts to familiar ones. Einstein used them generously in his writing:

> I stand at the window of a railway carriage which is travelling uniformly, and drop a stone on the embankment, without throwing it. Then, disregarding the influence of air resistance, I see the stone descend in a straight line. A pedestrian who observes the misdeed from the footpath notices that the stone falls to earth in a parabolic curve. I now ask: Do the "positions" traversed by the stone lie "in reality" on a straight line or on a parabola?

Einstein's analogy is so much more alive than the abstract question: Where do positions of an object actually lie [11]? Unfortunately, many scientific documents are devoid of analogies. One reason is that analogies demand creativity and confidence. Still, the best scientists and engineers use them. Analogies not only help readers understand concepts, but they also provide insights into how writers think. Consider an analogy by Maria Goeppert Mayer for her shell theory of the nucleus, which explains the small, but measurable differences in energy orbits for neutrons and protons [12]:

> To understand the shell theory of the nucleus, imagine a roomful of couples waltzing in circles, each circle enclosed inside another. These couples represent pairs of neutrons and protons. As the couples orbit the room, they also spin like tops, some clockwise and some counterclockwise. In a waltz, it is easier to spin in one direction than in the other direction. Thus the couples spinning in the easier direction will need slightly less energy than the couples spinning in the more difficult direction. The same is true for neutron–proton pairs in the nucleus.

Besides providing analogies to explain ideas, you will find opportunities to provide analogies to show the significance of numerical findings:

> In the brightness tests, the maximum retinal irradiance was less than 0.064 w/cm$^2$, a brightness about that of a household light bulb.

> Kruger National Park in South Africa contains about 19,500 square kilometers, which is larger than the states of Connecticut and Rhode Island combined.

Numerical analogies make your writing unique. Consider how Feynman gives significance to the magnitude of electrical forces [13]:

> If you were standing at arm's length from someone and you had one percent more electrons than protons, the repelling force would be incredible. How great? Enough to lift the Empire State Building? No. To lift Mount Everest? No. The repulsion would be enough to lift a weight equal to that of the entire earth.

## Anchor illustrations in the familiar

Anchoring your illustrations in the familiar is also important. If your illustrations raise questions that your text does not answer, you will frustrate your readers. To make your illustrations familiar, you should consider what your audience does and does not know. Because you have spent months, perhaps years, on your project, this task is not easy. Nonetheless, you should find a way to see your illustrations as your readers see them—with fresh eyes.

Too often, engineers and scientists miss the opportunity to show the relative size of an image by including either a scale or familiar-sized image alongside the depicted image. Although an audience may read in the caption of Figure 6-2 that each mirror array has a surface area of 39 square meters, the audience will probably not appreciate this size without a photo such as in Figure 6-3 that shows something familiar—in this case, the two men in the foreground [14].

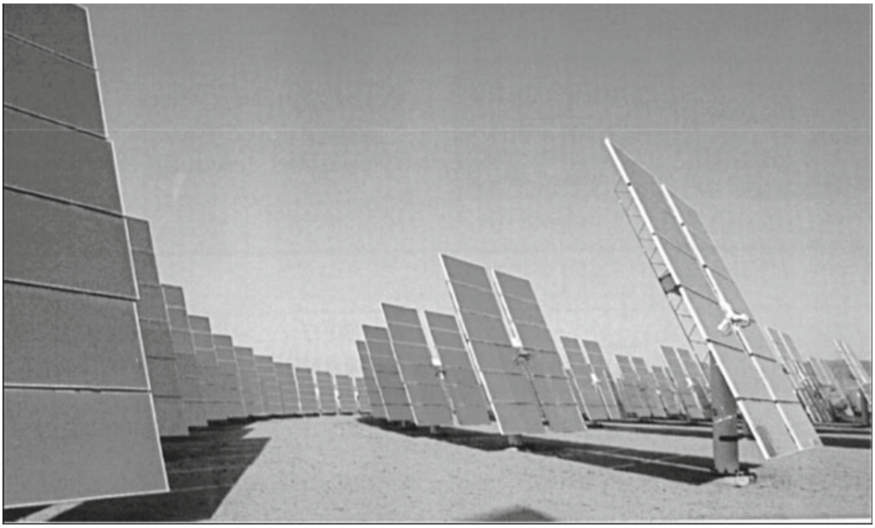

**Figure 6-2.** Solar mirrors at the Solar One Power Plant. Each mirror stand has a surface area of 39 square meters. *Although beautiful, this photo fails to convey how large 39 square meters is.*

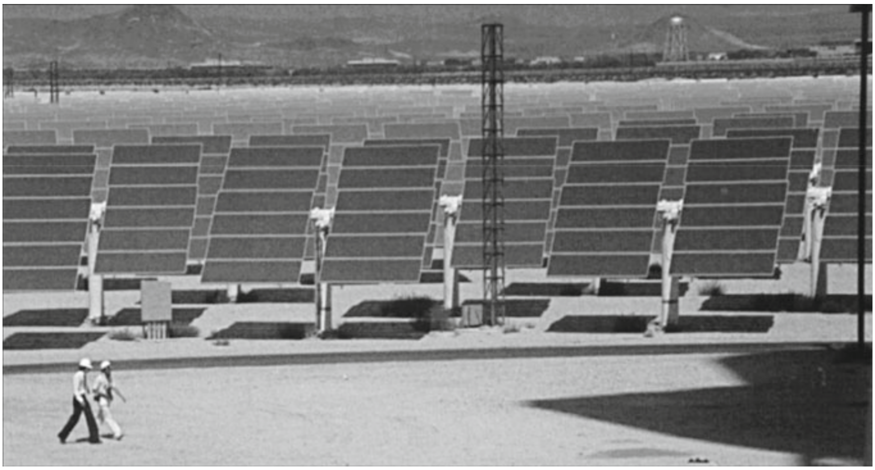

**Figure 6-3.** Solar mirrors at the Solar One Power Plant. Each mirror stand has a surface area of 39 square meters. *Showing the two men reveals how large the mirrors are.*

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Lesson 7

# Organizing the Content for the Audience

*The writing aspect of scientific research is exhausting…I have rewritten many parts of papers four to six times, restructuring the entire organization, before I finally become satisfied* [1].

—Hermann Helmholtz

In *The Sound and the Fury*, William Faulkner tells the same story behind three different brothers—one who is mentally disabled, another who is in despair, and yet another who is untrustworthy. Although the organization is difficult for the audience to grasp, the different perspectives provide a cascade of insights into the family. While audiences in fiction will tolerate a wide variety of organizational strategies, audiences in scientific writing will not. For instance, because audiences for research papers expect the author to follow the scientific method, research papers have a rigid organization: the research hypothesis (or question), the methods for testing that hypothesis, the results of that testing, and the meaning of those results. Certainly, side trails exist to account for such additions as theory, but the main path remains the same.

The organization of a general scientific document, on the other hand, is not so well defined, but most scientific papers


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_7

and reports have four common elements that this chapter analyzes: title, introduction, middle, and conclusion. Ideally, the title specifies the scope of the document so that readers can determine what the document contains. The introduction then prepares the audience for the document's middle, which essentially tells the story of the work in a logical and persuasive way. Finally, the conclusion summarizes the middle and gives a future perspective.

Not included in this lesson are two other important elements of a scientific document's organization: the summary and the appendices. Because those two parts are so connected to the emphasis of details, they are addressed in Lesson 8. Also not included in this lesson are the organizations of special documents, such as emails, instructions, and proposals. The organizations of those three types of documents appear in Lesson 9.

## A title specifies the scope of the work

A document's title is the single most important phrase in a document. Based on the title, audiences decide whether to read the document. How should you write a title in scientific writing? When I pose this question in my writing courses, a number of engineers and scientists rattle off a cryptic description commonly taught in grade school: "short and sweet." Although I am not exactly sure what "sweet" means, I am confident that this description does not apply to titles in scientific writing. As evidence, engineers and scientists who try to create such titles for their documents usually miss the mark, as this engineer did:

> Reducing the Hazards of Operations

What is this report about? Only a psychic would know. If this title came up in a list of titles from a computer search, would scientific audiences spend time retrieving this document? No.

In scientific writing, a title engages the audience by identifying the scope of the document. In other words, the title identifies what the document contains, and an audience interested in that scope will continue to read, while an uninterested audience will not. Your goal in writing a title is not to entice as many people as possible to read your work, but to engage those people who want or need to read your work. Given that scientific documents are often specific, specifying the scope in a single phrase is challenging. As evidence, most introductions to scientific papers and reports spend several sentences defining the scope. Still, the effort to specify the scope in a single phrase is worthwhile, because titles are so important.

Ideally, a strong title for a scientific paper or report orients readers by (1) identifying the field of work for the document and (2) separating that document from all other documents in that field. In doing so, a strong title incorporates details of the work that connect with the audience. A good test for a title is the way that it reads in a list of titles recovered by a computer search. In such a list, an effective title engages the targeted audience, while a weak title does not.

To appreciate this definition for a title, first consider an example from a journal article that does not succeed:

> Effects of Humidity on the Growth of Avalanches

Although this title is more specific than the earlier example, this title still does not meet the first criterion. On the basis of this title, most readers would assume that this document is about snow or rock avalanches in a mountainous terrain. As it turns out, this document focuses on electron avalanches in electrical gas discharges. For that reason, a better title would have been

> Effects of Humidity on the Growth of Electron Avalanches in Electrical Gas Discharges

Just because a title names the field of study does not mean the title is strong. Naming the field of study brings your audience to the right mountain, but your audience still does not know what portion of the mountain you will explore. In other words, you should address the second criterion, which is to separate your work from everyone else's. Consider the following example from another journal article:

> Studies on the Electrodeposition of Lead on Copper

Although this title orients the audience to the field in which the work was done (the plating of lead onto copper), this title is still unsuccessful. Somehow, the writer has to distinguish this work from other work in the field. For the work that this paper happened to discuss, a better title would have been

> Effects of Rhodamine-B on the Electrodeposition of Lead on Copper

Now, this title orients readers to the area of work and gives a specific detail (effects of rhodamine-B) to distinguish this work from other work in the field.

So far, the revisions have created longer titles. Can a title be too long? Absolutely. Because readers can process only so many details in a single phrase, you have to limit the number of details. Consider the following article title that presents too many details:

> Effects of Rhodamine-B and Saccharin on the Electric Double Layer During Nickel Electrodeposition on Platinum Studied by AC-Cyclic Voltammetry

This title overwhelms the audience. In a strong title, you should balance each detail's contribution against the space it acquires. In this title, certain details were not important enough to include. For instance, in this research, the specific names of the organic agents (rhodamine-B and saccharin) were not that important, because the chemist had simply selected two organic agents off the shelf. In addition, the detail about the electric double layer was secondary and, therefore, did not warrant inclusion. Put another way, the real estate in titles is too valuable for secondary details. Focusing on primary details, the author would have done better writing the following title:

> Using AC-Cyclic Voltammetry to Study How Organic Agents Affect the Electrodeposition of Nickel on Platinum

Without being too long, this title identifies the scope of the work. The title also emphasizes the unique element of the research: AC-cyclic voltammetry. To do so, the title placed that detail first. In a title, the heaviest emphasis occurs on the first detail and the last detail. As stated a number of times in this book, where text borders white space is where you achieve emphasis.

When you have a larger number of essential details, one strategy to help the audience sort those details is to use a colon within the title:

> Baltica from the Late Precambrian to Mid-Paleozoic Times: The Gain and Loss of a Terrane's Identity

In this title [2], the colon provides a break that allows the audience to treat the title as two lists of details as opposed to one long one. The details on the left side of the colon define the area of the work, and the details on the right of the colon distinguish this document from other documents in the area.

When writing titles, many scientists fall in love with technical terms and forget about the importance of the small words that audiences need to sort those technical terms. Unfortunately, strings of technical terms are difficult to read:

> 10 MWe Solar Thermal Electric Central Receiver Barstow Power Pilot Plant Transfer Fluid Conversion Study

What is this document about? Perhaps, we can guess that a solar energy plant is involved. Does this title orient? No, it overwhelms. Many details are included, but we have no sense of the relationship of those details. This document actually proposed a new heat transfer fluid for the Solar One Power Plant, which at that time was the world's largest solar power plant. Given that, a stronger title would have been

> Proposal to Use a New Heat Transfer Fluid in the Solar One Power Plant

Notice how this revised title contains short words—*to*, *a*, *in*, and *the*—interspersed among the technical terms. These smaller words show the relationship of details to one another. Notice also that this document was a special situation, a proposal, as opposed to the typical situation of a report or article. By identifying special situations such as proposals, progress reports, requests, and instructions in the titles, you orient the audience to the specific purposes of those documents.

Finally, in some disciplines such as biology, the acceptable form of a title is not limited to a phrase. A sentence is also accepted. As my sixth-grade English teacher, Mrs. Hutton, would say, "A sentence is much more powerful than a phrase." Because of the verb, a sentence can provide action. If your document distills to a single takeaway message, consider writing your title as a sentence:

> Colonoscopic screening for colorectal cancer improves quality of life measures

The power of such a title is that the audience immediately walks away with the most important result of your work [3]. If the format allows, you should capitalize a sentence title as you would a sentence—in other words, capitalizing only the first word of the sentence. Such a capitalization clues the reader early on that the group of words is a sentence. Also, many formats that allow sentence titles justify the title on the left margin for easier reading.

## The introduction prepares readers for the middle

To prepare the audience for the document's middle, the introduction answers questions that readers have at the beginning:

> What exactly is the work?
>
> Why is the work important?
>
> What is needed to understand the work?
>
> How will the work be presented?

Granted, an introduction might not explicitly address all four questions. Depending on the content and the audience, the introduction might address only two or three of the questions. Also, for most scientific documents, the best order to answer the questions is not the one listed above. As with other questions about style, how you begin depends on the content and audience. Although introductions vary in the type and order of information, you should design your introduction such that readers do not reach the middle of your document with any of these four questions lingering.

**What exactly is the work?** Your introduction is your first chance to define the full boundaries of your work. In the introduction, you are not cramped by space as you are in the title. Therefore, you should take advantage of the opportunity:

> This paper presents a model to describe the electrical breakdown of a gas. We call this model the two-group model because of the similarity between the problem of gas breakdown and the problem of neutron transport in nuclear reactor physics. The two-group model is based on electron kinetics and applies to a broad range of conditions (breakdown in pure gases, for example). The model also provides a continuous picture of the initial phase of breakdown above the Townsend regime, both in structure of the breakdown and in the physics of the processes [4].

This introduction gives details about the work that could not fit into the title or summary, details such as where the theory got its name and the theory's relation to other theories.

When you identify your work in your introduction, you should specify the work's scope and limitations. As stated earlier, the scope identifies what the document contains. In contrast, the limitations are the assumptions that restrict the scope's boundaries. Scope and limitations usually go hand in hand. Often, when you identify a project's scope, you implicitly state what the limitations are. Sometimes, though, the limitations must be explicitly stated:

> In this paper, we compare the life expectancies of three different groups of people: heavy alcohol drinkers, moderate alcohol drinkers, and people who do not drink alcohol. Not considered, however, are the social, medical, or economic makeup of these groups—three elements that could affect life expectancies significantly more than alcohol intake.

The first sentence of this example specifies the scope, and the second sentence specifies the limitations. The authors explicitly stated the limitations (assumptions, in this case) because the readers likely would not have inferred those assumptions from the scope.

**Why is the work important?** In scientific documents, a common mistake is to launch into the nuts and bolts of the work without showing the work's importance. The result is that many readers do not finish the document because they lack the incentive to tackle the difficult portions. Reading scientific documents is hard work, and readers need reasons to keep going. Showing the importance of the work provides an incentive.

Another reason to show the importance of the work is financial. Most scientific projects depend on outside funding, and before someone will give away money, she or he has to be convinced that the work is important. Often, that particular someone will be someone outside science. Justifying your work to someone outside science can be difficult. You cannot get away with just saying the work is important, as this physicist tried to do:

> This paper presents the effects of laser field statistics on coherent anti-Stokes Raman spectroscopy intensities. The importance of coherent anti-Stokes Raman spectroscopy in studying combustion flames is widely known.

This introduction persuades the readers of nothing. Instead of just telling readers that the work is important, you should show readers the work's importance, as this chemist did [5]:

> This paper presents a design for a platinum catalytic igniter in lean hydrogen-air mixtures. This igniter has application in light-water nuclear reactors. For example, one danger at such a reactor is a loss-of-coolant accident, in which large quantities of hydrogen gas can be produced when hot water and steam react with zirconium fuel-rod cladding and steel. In a serious accident, the evolution of hydrogen may be so rapid that it produces an explosive hydrogen-air mixture in the reactor containment building. This mixture could breach the containment walls, allowing radiation to escape. To eliminate this danger, one proposed method is intentionally to ignite the hydrogen-air mixture at concentrations below those for which any serious damage might result.

Although most projects have practical applications, much excellent work exists for the sole purpose of satisfying curiosity. In such cases, you cannot assume that your readers already share your curiosity. You must instill that curiosity. In effect, you should raise the same questions that made you curious when you began the work [6]:

> In size, density, and composition, Ganymede and Callisto (Jupiter's two largest moons) are near twins: rock-loaded snowballs. These moons are about 5000 km in diameter and contain 75 percent water by volume. The one observable difference between them is their albedo: Callisto is dark all over, while Ganymede has dark patches separated by broad light streaks. This paper discusses how these two similar moons evolved so differently.

How much space should you devote to justifying your work? That answer depends on your audience. If your readers are experts in your field, you may not have to justify your work explicitly. In other words, your readers might implicitly understand the importance. However, not justifying your work limits your audience. Your audience, in essence, becomes only those experts.

**What is needed to understand the work?** The third question that readers expect an introduction to answer is what background information the introduction should provide. That answer depends on your readers and how much they know about your work. For instance, if you are writing about the effects of a long-duration space mission on the human immune system and if your main audience is a general scientific audience, then much of the background would be on the human immune system itself. However, if your principal audience consists of immunologists, then much of the background would be on something else, perhaps a review of the immunology findings from previous space missions.

In general, the less your audience knows about your subject, the more difficult it is to write the background section. Unless you plan to spend the rest of your career on one document, you cannot begin at the lowest stratum of science with Euclid or Archimedes and cover everything in between. You have to be selective. For instance, if it were 1913 and you were Niels Bohr writing the theory of the hydrogen atom, you might assume your readers were familiar with Balmer's equation for wavelength and Coulomb's law of force, but not with Rutherford's nuclear model for the atom, which was proposed in 1911. You might then start your paper at an "elevation of knowledge" somewhere just below Rutherford's work.

In a research document, the audience expects a particular type of background called the literature review. In many research papers, this review appears as a couple of paragraphs in the introduction. In some journals, lengthier reviews appear as a separate section later in the paper. Likewise, in a dissertation, the literature review is usually an entire chapter. No matter where the review occurs in the document, this portion serves several goals. One goal is to credit other researchers in the field. Another goal is to provide background so that the reader can understand the work. Still, a third goal to build credibility for the author—in effect, showing which papers are most important in a field boosts the credibility of that author. However, the most important goal of a literature review for a research document is to show that the research is unique.

The question of whether the research is unique is a criterion that most research journals use for acceptance of articles. Given that, the literature review should explicitly show that uniqueness. To do so, you do not simply state what others have done. Rather, you also show the gaps that other researchers have not filled.

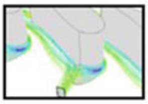
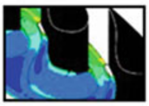
One caution for a literature review is that identifying the gaps in the research might offend other researchers in the area. In other words, if not written with sensitivity, a sentence identifying a lack of accuracy in a measurement might offend the researcher who took that measurement. Avoiding such offenses is important because chances are that at least one of those researchers in the literature review will be a reviewer for your paper. For that reason, you should discuss the gaps or shortcomings in the work of others in a respectful manner.

> The high freestream turbulence levels of interest (20 percent) cannot be generated and sustained by standard techniques for generating turbulence. The only study that has achieved turbulence levels greater than 20 percent was done by Maciejewski and Moffat [7]. Recognizing the need for any data that would indicate the effects of high freestream turbulence on heat transfer, Maciejewski and Moffat placed a test plate along the edge of a turbulent free jet. While this experimental condition had the advantage of producing high freestream turbulence, it had definite drawbacks in that the mean velocity field was non-uniform and decayed rapidly along the test plate. Ideally, what is needed is a device for producing high freestream turbulence that has a uniform mean velocity field and that does not decay rapidly downstream [8].

Here, the authors showed the drawbacks of the work by Maciejewski and Moffet, but in a way that would not offend.

One final comment on literature reviews is that for the review of a longer research document such as a dissertation, I recommend including a table that shows the contribution of each paper (or research group) on a separate row. In other words, the first row would include distinguishing information for one paper: the names of the authors and distinguishing aspects, such as voltage range or experimental technique, of that paper. Each row would present similar information for the remaining papers, with the last row containing the distinguishing aspects of your research. When well constructed, this table readily shows how your research differs from everyone else's research. Moreover, such a table provides an effective answer to the reviewer's question, is your research unique? Appearing in Table 7-1 is an excerpt from a longer such table. In this table, the author (Stephen Lynch) included his own thesis work on the bottom row. As Table 7-1 shows, Lynch's techniques are distinct from the other listed researchers.

**Table 7-1.** Experiments on leading-edge geometries for turbine vanes [9].

| Researchers | Geometry | Technique |
|---|---|---|
| Zess and Thole<br>[2001] |  | Flow-field measurements<br>Boundary conditions: 2-dimensional |
| Becz et al.<br>[2003] |  | Total pressure loss measurements<br>Boundary conditions: 2-dimensional |
| Lynch<br>[2006] |  | Heat transfer measurements<br>Wall shear stress measurements<br>Boundary conditions: 3-dimensional |

For scientific documents that do not present research, the type of background information provided in the introduction can vary much. For instance, many documents are best served by having the background paragraphs of the introduction contain definitions or explanations of principles. Note that not that all background information has to appear in the introduction. If you have multiple background topics, your document often will read more efficiently if in the introduction, you restrict yourself to the background that applies to the entire document. In contrast, if the background is pertinent to only one section of the middle, then you should place that background within that one section.

In addition, if the background pertains to the entire document, but is lengthy, you might place that background information in a separate section following the introduction. That way, the background does not overwhelm the other aspects of the introduction. If you do create such a section, you should select a section title that reflects the scope of that section. In other words, rather than choosing "Background," which could mean a host of things, you should choose "Literature Review," "Timeline of Eruption," "Habitat for Snow Leopard," or whatever accurately describes the information.

**How will the work be presented?** The last expectation that an audience has for an introduction is the mapping of the document. In general, the longer a document is, the more important the mapping of the work becomes. This principle is not only true for scientific documents, but for scientific presentations as well. Consider the mapping for a journal article about a nuclear winter:

> This report discusses the effects of smoke on the earth's climate following a large-scale nuclear war. In the first section of the report, we present a war scenario in which 10,000 megatons of high-yield weapons detonate. The second section of the report then introduces assumptions for the amount of smoke produced from resulting fires, the chemical characteristics of the smoke, and the altitudes at which the smoke initially enters the atmosphere. Presented in the third section are computer models that show how the smoke distributes

itself in the weeks and months following the war. Finally, in the fourth section, we discuss how the earth's climate changes as a result of that smoke distribution [10].

You might ask what is the point of mapping a report in the introduction of a report, when a table of contents for that report has already done so? Similarly, you might wonder in a research paper, what is the importance of mapping the paper when the audience already knows that the paper will follow the general order of methods, results, and discussion? Three reasons exist. First, by mapping the document at the end of the introduction, you make a nice transition from the beginning of the document to the document's middle. Second, in many documents, the reader desires your reasoning for ordering the document as you did. For instance, in an evaluation report, why do you discuss Option A before Option B? Third, the mapping paragraph is an opportunity to emphasize details in each section. For instance, the mapping of the nuclear winter document emphasized the three assumptions for the computer models.

## The middle presents the work in a logical and persuasive fashion

In the middle of a scientific document, you state what happened as well as how it happened. For instance, in a research paper, the middle presents the methods for testing the hypothesis, the results of the test, and the meaning of the results. In longer documents, you break the middle into sections that reveal the strategy and depth. The middle reveals those strategies through the headings of sections and the arrangement of paragraphs within those sections. How much depth you provide depends on the expectations of the audience and the document's constraints for length.

**Choose appropriate strategies.** Throughout a scientific document, you interweave the logical strategies that you learned in high school: chronological, spatial, flow of a variable, cause and effect, and classification and division. Note that choosing a strategy for a document is not a paint-by-numbers decision.

You cannot pull out a chronological strategy for instructions or a spatial strategy for equipment specifications and expect the strategy to work every time. For each document, you should select a strategy that is appropriate for the content and the audience. In effect, selecting a strategy is often a trial-and-error process. You envision a path, you try it, and then you look back to see whether the strategy works.

One of the most common strategies is the chronological strategy, which follows the variable of time. Chronological strategies are seen in discussions of timeline processes and cyclic processes. For instance, in a timeline process for the evolution of Hawaiian volcanoes, you would follow the development of the volcano through its eight life stages. Likewise, in the cyclic process for the orbit of a comet, you would designate a beginning to the orbit and follow the process until it completes the cycle.

In both situations, you should assign markers that divide the process into stages. When dividing a process into stages, you should try to group the stages into divisions of twos, threes, or fours so that your audience can remember those divisions. A list with more than four items taxes the reader's memory. How then would you handle a situation, such as the Hawaiian volcano, in which you have eight steps? One way is to break the list of eight into two lists of four: the building stages and the declining stages [11]. In the building stages, the volcano develops from the sea floor to a volcano above sea level (Kilauea is a good example of a volcano in the building stages). In the declining stages, the volcano deteriorates because of erosional effects (Oahu exemplifies a volcano in the declining stages).

- Building Stages
    - Explosive Submarine Stage
    - Lava-Producing Stage
    - Collapse Stage
    - Cinder Cone Stage

Declining Stages
- Marine and Steam-Erosion Stage
- Submergence and Fringing-Reef Stage
- Secondary Eruptions and Barrier-Reef Stage
- Atoll and Resubmergence Stage

Another common strategy is the spatial strategy. Here, the strategy follows the physical shape of a form or object: the curvature of a fossil, the dispersion of a volcano's ash plume, or the shape of a comet. As with chronological strategies, you would want to divide the form into two, three, or four distinct parts. For instance, in describing a comet, a logical division is its head, coma, and tail.

A third common strategy in science is to follow the flow of a variable, such as energy or mass, through a system. Consider, for example, the nuclear fusion experiment in Figure 7-1. On a first draft for this system, you might select a spatial strategy in

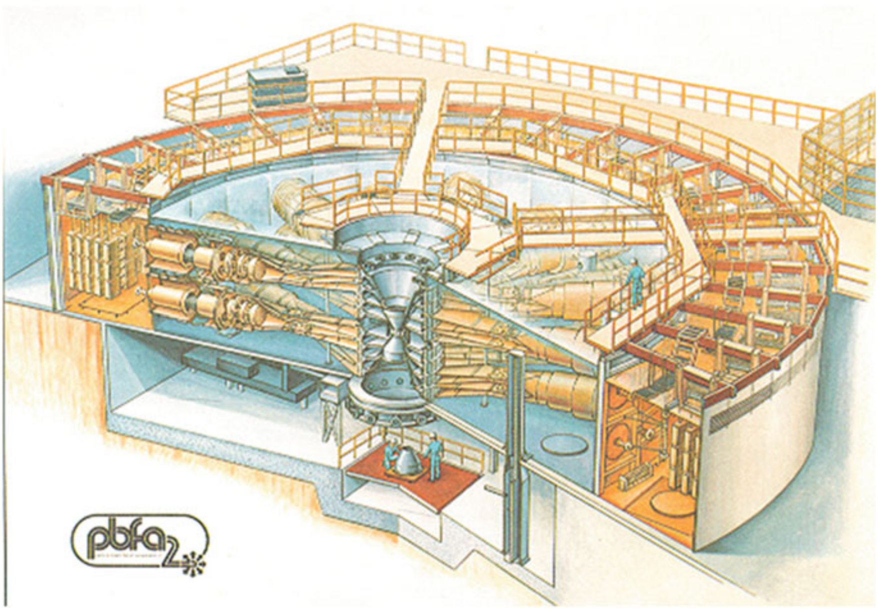


**Figure 7-1.** Cutaway of nuclear fusion experiment at Sandia National Laboratories [12]. Here, an accelerator focuses lithium ions onto deuterium–tritium pellets in an attempt to produce nuclear fusion.

which you begin with the circumference of the experiment and then work your way radially inward. Given the complexity of this experiment, though, this strategy proves cumbersome. A better strategy would be to follow the flow of energy through the system. This strategy reduces the experiment from three dimensions to one dimension. In this strategy, you follow the energy as it changes from electrical energy to particle beam energy and then to fusion energy As with the first strategy, you end up moving radially inward, but unlike the first strategy, you have your audience thinking in one dimension rather than three.

In scientific writing, most organizational problems do not arise because the chosen strategies are illogical. Rather, most problems arise because the logical strategies chosen are inappropriate for the audience. In describing the nuclear fusion experiment, the flow of energy from electrical energy to fusion energy works well for a technical audience. However, for a nontechnical audience, such as the United States Congress, which is deciding whether to fund this project, you might reconsider this strategy. Because Congress thinks of the project as a nuclear fusion project, you might begin with the fusion energy rather than with the electrical energy:

> In our design for producing nuclear fusion, we compress tiny deuterium-tritium pellets, which are about the size of BBs. To compress these pellets, we require the energy of a focused beam—in our design, a beam of lithium ions. Producing this particle beam requires a huge pulse of electrical energy, which is supplied here by a Marx bank generator.

For this nontechnical audience, we have moved backward from the recognized goal of producing nuclear fusion to the unfamiliar steps of generating a particle beam and charging a Marx bank generator.

Perhaps the most common strategy in scientific writing is the classification and division strategy. In this strategy, you group items into parallel parts. Examples abound in the animal kingdom. Take the example of the four species in the Panthera genus:

| | |
|---|---|
| Tigers | *Panthera tigris* |
| Lions | *Panthera leo* |
| Jaguars | *Panthera onca* |
| Leopards | *Panthera pardus* |

The most important considerations for this strategy are that the items are parallel to one another and that the list is not too long. If the list is more than four items, you should consider another classification level such as what was suggested for the stages of a Hawaiian volcano.

Cause-effect organizations and comparison–contrast organizations also occur in scientific writing. Cause-effect organizations serve documents in which you investigate why things happened, such as why the *Titanic* sank so quickly. Likewise, comparison–contrast organizations serve documents in which you evaluate a number of options, such as an evaluation of lifeboat designs for a cruise ship.

**Create descriptive headings.** For scientific documents that are longer than a couple of pages, having sections becomes important. Why? One reason is that sections can help reveal the strategy of the document. The headings act as a roadmap for readers. When the headings are well written, the audience can readily see the document's organization.

Sections also provide readers with white space. Readers of scientific papers and reports need white space so that they have time to rest and reflect on what they have read. Besides showing the strategy and providing white space, sections allow readers to jump to information that interests them. Along the same lines, having sections allows your readers to skip information that does not interest them. Remember: The primary purpose of your writing is not to entice the audience into reading every word you have written, but to inform and persuade your audience as effectively as possible.

How long should your sections be? As with most questions about style, no absolute answer exists. However, if your sections are too long to read in one sitting, your readers will tire in the same way that a driver tires from a long stretch of highway. On the other hand, if your sections are too short, your paper or report will appear as a collage of headings. The unnecessary white space will cause your readers to make too many starts and stops. The overall effect is that your readers will tire much in the same way that a driver tires from the starts and stops of congested city traffic.

One organizational mistake that young engineers and scientists make is to jump to having subsections in a section without considering whether paragraphs themselves could show the organization. Put another way, you should avoid having subsections when paragraphs could do the job. Whereas a sentence states a single idea, a paragraph states a group of connected ideas. Particularly in persuasive documents, you should lean toward using paragraphs to reveal a section's organization. For instance, consider a section that discusses the features of the species in the *Panthera* genus that allow them to roar:

Paragraph mapping two features of *Panthera* genus that allow roaring
Paragraph that describes cranial features and larynx of tigers
Paragraph that describes cranial features and larynx of lions
Paragraph that describes cranial features and larynx of jaguars
Paragraph that describes cranial features and larynx of leopards
Paragraph that concludes

How should you title a section? Precision and clarity should be your guide. Do not resign yourself as many scientists and engineers do to cryptic one-word titles:

Slurry
  Combustion
  Pollution
Dry
  Combustion
  Pollution

These titles are vague. Because readers often skim through documents to look for particular results, you want your headings to indicate the sections where those results can be found.

Coal-Water Slurry
  Combustion Efficiency
  Combustion Emissions
Dry Pulverized Coal
  Combustion Efficiency
  Combustion Emissions

When creating titles for sections, you should also consider the parallelism of the titles. In other words, do not write

Mining the Coal
Transportation Stage
Burning the Coal

The second heading is not parallel to the other two. Think of your sections as pieces of a pie. It makes no sense to slice a pie and have one piece be apple and another piece be cherry. If your first subsection title is a noun phrase, then all the subsection titles of that section should be noun phrases. Likewise, if your first subsection title is a participial phrase, then all the subsection titles of that section should be participial phrases.

| **Noun Phrase** | **Participial Phrase** |
|---|---|
| Mining Stage | Mining the Coal |
| Transportation Stage | Transporting the Coal |
| Combustion Stage | Burning the Coal |

Finally, if you break your information into one section, you must have a second. Having a single section or subsection is similar to slicing a pie and ending up with only one piece:

Precombustion Processes
  Coal Cleaning
Combustion Processes
Post-combustion Processes

Because “Coal Cleaning” has nothing to be parallel to, this breakdown is inherently nonparallel. You should either include another subsection beneath “Precombustion Processes,” such as “Coal Switching,” or drop the “Coal Cleaning” subsection:

Precombustion Processes
    Coal Cleanings
    Coal Switching
Combustion Processes
Post-combustion Processes

Precombustion Processes
Combustion Processes
Post-combustion Processes

A good test for headings is how well they reveal the organization of the document when they stand alone as a table of contents. If they do not reveal the organization, then you should reconsider them. In the following example from a progress report on the forensic investigation of Pan Am Flight 103, the weak headings on the left suffer from a number of problems: vague descriptions, nonparallelisms, and single-item subheadings.

**Weak Headings**
Introduction
Debris Recovered
Cataloguing
Interpretation
Results
    Placement
    Bomb Makeup
Work to be Done
    Interpretation

**Strong Headings**
Introduction
Completed Work
    Recovering Debris
    Cataloguing Debris
    Interpreting the Debris
Preliminary Results of Work
    Placement of Bomb
    Construction of Bomb
Future Work

In the revision on the right, notice the parallelism on the heading level and in each subheading grouping. Also, notice that the revision reveals the overall strategy for the document.

**Choose an appropriate depth.** In addition to the order of information, you should think much about the depth. Depth is the level of detail that you, the writer, provide for a subject. As mentioned earlier in this book, the occasion—specifically, the length of the document—affects depth. For instance, the more pages that a research journal allows, the more detail that you can include about your research project.

Also affecting depth is the audience. If the reader desires much depth about the topic, you should provide it. However, as you present details about a subject, you also spawn questions about the subject. For that reason, achieving a proper depth means finding a level such that you satisfy the reader's interest and anticipate the reader's questions. Consider the following three depths for the same topic:

> Depth 1: The Environmental Protection Agency has tightened emission standards by 60 percent.
>
> Depth 2: The Environmental Protection Agency has tightened emission standards from 0.25 g/hp-h to 0.1 g/hp-h. The particulates include hydrocarbons, carbon monoxide, and nitrogen oxides.
>
> Depth 3: The Environmental Protection Agency has tightened emission standards by 60 percent: from 0.25 g/hp-h (grams of particulate/horsepower-hour) to 0.1 g/hp-h. The particulates include hydrocarbons, carbon monoxide, and nitrogen oxides. All three particulates are considered pollutants.

Of these three depths, the first is the most shallow because it gives the least amount of information, and the third depth is the deepest because it gives the most information. Although the second depth is deeper than the first depth, it is the least successful because it raises unanswered questions—namely, what does the abbreviation "g/hp-h" mean? In a sense, this depth is simultaneously too shallow and too deep. Once you raise questions at a certain depth, you are obliged to answer those questions.

The technical level of the audience is a second way in which audience affects depth. The more technical the audience is, the more quickly you can achieve a technical depth because with a technical audience, you need not provide as much background as you do with a nontechnical audience.

Yet another important effect on depth arises not from occasion or audience, but from purpose—namely, how persuasive the document is. For instance, in an informative paper about how effective photorefractive keratectomy has been at correcting nearsightedness, you simply present the results of the procedure. However, in a paper arguing for approval of the technique, you go deeper to include rebuttal arguments for the problems that the procedure has. You would also include a discussion about the advantages that photorefractive keratectomy has over options.

One quick check for the depth of a document is to examine the lengths of paragraphs and sections. In general, the longer the paragraphs and sections, the greater the depth that is achieved. When paragraphs and sections are short, the initial impression given to the audience is that the document lacks depth. In some cases, though, the audience does not expect much depth. For example, in a set of instructions, the audience is primarily concerned with the surface question of *how* rather than the deeper question of *why*. For that reason, instructions often have short sections and short paragraphs that focus on the question of *how*. In contrast, journal papers, formal reports, and proposals confront both questions of *how* and *why*. Correspondingly, the sections and paragraphs of those documents are longer.

Can sections and paragraphs be too long? In scientific writing, the answer is yes. Although a fiction writer such as William Faulkner can pull off a four-page paragraph, a scientific writer cannot. A scientific writer has to divide the information into digestible portions separated by white space. Otherwise the reader tires, and the efficiency of understanding goes down.

A good rule of thumb is that short paragraphs are 6 lines or fewer, medium-length paragraphs are 7–11 lines, and long paragraphs are 12–15 lines. Using these lengths as guidelines, you should aim for a variety of lengths with the largest number of paragraphs falling in the medium range. Unless you are writing special documents such as correspondence and instructions, you want to avoid stacking more than two short paragraphs because that arrangement conveys a lack of depth. At the other extreme, you should avoid paragraphs longer than 15 lines, because such a length intimidates readers. An exception here might be a paragraph that contains an equation set off on its own line, because the white space surrounding the equation provides a visual break for the reader.

Finally, once you establish a depth in discussing a topic, readers expect you to maintain that depth for the discussion of related topics. Maintaining a balance of depth is particularly important in comparisons.

## The conclusion summarizes the middle and provides a future perspective

Just as readers have specific expectations for the introduction, readers have specific expectations for the conclusion section. The first expectation for the conclusion section is an analysis of the most important results from the document's discussion. The second expectation is a future perspective on the work.

In the conclusion's summary, you generally analyze the results as a whole, rather than individually as you did in the discussion. Note that in this analysis you should not act like Perry Mason and bring in new evidence that unravels the mystery of your project. In other words, the conclusion's analysis should arise from the findings presented in the middle.

Besides presenting an analysis of the important results in the conclusion section, you also provide a future perspective on the work. In some documents, that future perspective might be recommendations. In other documents that future perspective might be a nod to the direction in which your work will head. A third kind of future perspective is to mirror the scope and limitations that you presented in the beginning of the document. In the document's beginning, you started with a "big picture" and focused until you reached the scope and limitations of the work. In the conclusion, you now take the work's results that you discussed in the document's middle and show the ramifications of those results on the big picture. In a sense, you complete a circle because in the document's beginning, you started with the big picture, and now you end with the big picture.

How long should a conclusion be? For a short paper, a conclusion might be only one paragraph or even one sentence:

> These tests showed that a non-powered igniter for lean hydrogen-air mixtures is feasible, and that such an igniter could contribute to the safety of light water nuclear reactors by igniting safe concentrations of hydrogen during a loss-of-coolant accident [5].

Typically, a conclusion section runs about 5 to 10 percent of the length of the main text.

Another way to look at a conclusion is to see it as bringing together the loose ends of your work. Although you often cannot tie everything into a neat package, you can convey a sense of closure for your audience. Put another way, you do not have to reach a peak in your conclusion, but you should reach a plateau.

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# Providing Proper Emphasis

> *If you have an important point to make, do not try to be subtle or clever. Use a pile driver. Hit the point once. Then come back and hit it again. Then hit it a third time — a tremendous whack* [1].
>
> —Winston Churchill

As mentioned in Lesson 1, several years before the fateful launch of the Space Shuttle Challenger, a NASA engineer had reservations about the O-ring design of the shuttle's solid rocket boosters. These O-rings served as a secondary seal to prevent hot combustion gases from escaping through the joints in the rocket boosters. After hearing those reservations, NASA management requested that the engineer seek opinions about the design from O-ring experts around the country. Given below is the short memo report that the engineer wrote to document the opinions from those experts. For the board investigating the Challenger accident, this memo report was the end of the paper trail for NASA's concern about the O-ring design of the solid rocket booster [2]. As you read this short report, think about why this report did not spawn further discussion among NASA managers about reservations in the O-ring design. Also, think about which details were the most important and how those details were emphasized.

> Subject: Visit to Precision Rubber Products Corporation and Parker Seal Company
>
> The purpose of this memorandum is to document the results of a visit to Precision Rubber Products, Lebanon, TN, by Mr. Eudy, EES1, and Mr. Ray, EP25, on February 1, 1979, and also to inform


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_8

you of a visit to Parker Seal Company, Lexington, KY, on February 2, 1979, by Mr. Ray. The purpose of the visits was to present the O-ring manufacturers with data concerning the large O-ring extrusion gaps being experienced on the space shuttle solid rocket motor clevis joints and to seek opinions regarding potential risks involved.

The visit on February 1, 1979, to Precision Rubber Products Corporation by Mr. Eudy and Mr. Ray was very well received. Company officials Mr. Howard Gillette, Vice President for Technical Direction, Mr. John Hoover, Vice President for Engineering, and Mr. Gene Hale attended the meeting and were presented with the SRM clevis joint seal test data by Mr. Eudy and Mr. Ray. After considerable discussion, company representatives declined to make immediate recommendations because of the need for more time to study the data. They did, however, voice concern for the design stating that the SRM extrusion gap was larger than that covered by their experience. They also stated that more tests should be conducted with the present design. Mr. Hoover promised to contact Marshall Space Flight Center (MSFC) within a few days. Mr. Gillette provided Mr. Eudy and Mr. Ray with the names of two consultants who may be able to help. We are indebted to Precision Rubber Products Corporation for the time and effort being expended by their people on this problem, especially since they have no connection with the project.

The visit to the Parker Seal Company on February 2, 1979, by Mr. Ray, EP25, was also well received; Parker Seal supplies the O-rings used in the SRM clevis joint design. Parker representatives Mr. Bill Collins, Vice President for Sales, Mr. W. B. Green, Manager for Technical Services, Mr. J. W. Kosty, Chief Development Engineer for R&D, Mr. D. P. Thalman, Territory Manager, and Mr. Dutch Haddock, Technical Services, met with Mr. Ray, EP 25, and were provided with the identical SRM clevis joint data as was presented to Precision Rubber Products Corporation on February 1, 1979. Reaction to the data by Parker officials was essentially the same as that by Precision: the SRM extrusion gap is larger than they have previously experienced. They also expressed surprise that the seal had performed so well in the present application. Parker experts would make no official statements concerning reliability or potential risk factors associated with the present design; however, their first thought was that the O-ring was being asked to perform beyond its intended design and that a different type of seal should be considered. The need for additional testing of the present design was also discussed, and it was agreed that testing which more closely simulated actual conditions should be done. Parker officials will study

> in more detail with other company experts and contact MSFC in approximately one week. Parker Seal has shown a serious interest in assisting MSFC with this problem and their efforts are much appreciated.

The opinions expressed by the two O-ring manufacturers confirmed the engineer's concern about the ability of O-rings to provide a secondary seal. However, the report failed to emphasize those opinions. Why? One reason was the wording. For instance, as discussed in Lesson 1, the wording of the title was not effective:

> Subject: Visit to Precision Rubber Products Corporation and Parker Seal Company

Not only did this title fail to connect the visit to the secondary seal of the shuttle solid rocket booster, but the title did not even hint that a potential problem existed. Because the managers who received this report likely were busy, many might not have been inclined to read beyond the title. A much stronger title would have been

> Subject: Concern by O-ring Manufacturers about the Secondary Seal Design in the Shuttle's Solid Rocket Boosters

A second reason that the report lacked proper emphasis was the lack of repetition of important details in the conclusion. Instead, the report ended abruptly. As mentioned in Lesson 7, the conclusion is an opportunity to restate the most important details. Also, lacking at the end of this report was a future perspective on what the audience should do next. As written, the report suggested that others would handle the problem. However, the problem remained unresolved and no one at NASA followed up.

A third reason that the report lacked proper emphasis was poor placement of important details. The two most important sentences in the report are in the middle of paragraphs. One sentence, which expressed a manufacturer's concern about the gap, occurs in the middle of the long second paragraph. The second sentence, which conveyed another manufacturer's surprise that the seal had performed so well, occurs in the middle of the long third paragraph. If you want to bury a detail in a report, place that detail in the middle sentence of a middle paragraph. Essentially, this report placed the two most important sentences in the report's two least important places.

At the hearings of the Challenger investigation board, the testimony of this author revealed that burying these concerns was *not* his intention [2]. So why did he structure his report this way? My suspicion is that he became caught up in writing a trip report, rather than in using this report to convey the concerns of experts to the intended audience. In other words, the engineer was so focused on the occasion that he neglected the audience and purpose.

## Emphasize details with wording

In weak scientific documents, many details float, ungrounded, because the author has not shown why the details were included:

> One of the panels on the north side of the solar receiver will be repainted with Solarcept during the February plant outage.

What is the most important detail here? Is it that the panel is on the north side? Is it that the panel is being repainted with Solarcept? Is it that the repainting will occur during the February plant outage? The problem with this sentence is that you do not know. In this sentence, which was a standalone item of a progress report, all details carried the same weight. Put another way, the author used five prepositional phrases to insert the details. Although prepositional phrases are valuable for incorporating details about time and position, a string of prepositional phrases does not provide emphasis. In other words, all five prepositional phrases in the above sentence carried the same importance.

In strong scientific writing, the writer shows the relative importance the details by giving reasons for their inclusion:

> Because the February plant outage gave us time to repair the north side of the solar receiver, we repainted the panels with Solarcept, a new paint developed to increase absorptivity.

In this revision, readers can see why the details are included. Understanding the *why* allows readers to assign an importance to the details. As mentioned in Lesson 5, one way to convey the *why* is by using infinitive phrases, which are verb phrases that begin with the word *to*:

> …to repair the north side…to increase absorptivity.

Using infinitive phrases helps show the causal relationship of details, which allows readers to infer the relative importance of those details.

In addition to using infinitive phrases to convey the *why*, professional writers also use dependent clauses introduced by words such as *because* and *although*:

> Because the February plant outage gave us time to repair the north side of the receiver,…

As stated earlier, a myth abounds that the word *because* cannot begin a sentence. No respected book on grammar offers this advice. Moreover, major publications such as *Nature* contain many sentences that begin with *because*. Professional writers begin sentences in this way because these writers want to emphasize important details.

## Emphasize details with repetition

Readers do not retain every detail in a document—far from it. However, mentioning a detail two or three times in the document helps to increase the likelihood of retention. For instance, if you have an important result in a report or paper, you should heed Winston Churchill's advice and mention it three times. Where you choose to repeat an important detail is strategic. The organization of most scientific documents allows you to mention the detail naturally in three places: the summary, the document's middle, and the conclusion.

Summaries are important for readers. As Winston Churchill also said, "Please be good enough to put your conclusions and recommendations on one sheet of paper at the very beginning of your report, so that I can even consider reading it [3].” In essence, a summary, often referred to as an abstract in research writing, gives away the results and lets the audience decide whether they want to read the document to learn how the author arrived at those results:

> This report describes a new inertial navigation system that will increase the mapping accuracy of oil wells by a factor of ten. Using three-axis navigation, the new system protects the sensors from high spin rates. The system also processes its information by Kalman filtering (a statistical sampling technique) in an on-site computer. Test results show that the three-dimensional location accuracy is $\pm$ 0.1 meters of well depth, an accuracy ten times greater than conventional systems.
>
> Besides mapping accuracy, the inertial navigation system has three other advantages over conventional systems. First, its three-axis navigator requires no cable measurements. Second, probe alignment in the borehole no longer causes an error in displacement. Third, the navigation process is five times faster because the gyroscopes and accelerometers are protected [4].

This summary is tight. It is a sum of the significant points, and only the significant points, of the project—note that every detail written in a summary is either a repetition or condensation of something in the main text of the document. This summary also stands on its own, independent of the report. For instance, the summary defined the unusual term “Kalman filtering.”

Although many names exist for summaries in scientific writing, essentially two types exist: informative summaries and descriptive summaries. An informative summary, often called an executive summary when written for management, is the type of summary depicted above. As in the example, informative summaries present a synopsis of the work. For that reason, an informative summary is analogous to a box score in baseball. In a box score, you gather the most important results of the game: how many runs, hits, and errors each team had. You also gather many secondary results such as who the winning and losing pitchers were and who hit home runs.

A descriptive summary, on the other hand, states what *kind* of information will occur in the document; it is a table of contents in paragraph form. A descriptive summary is like the byline to a baseball game, such as the opening game of the 1971 World Series:

> Pittsburgh (Ellis, 19-9) versus Baltimore (McNally, 21-5)

From the byline, you know what is going to happen— which teams will play, who will be the pitchers, and what their records are. Descriptive summaries give the same kind of information about the document, namely, what the document will cover:

> **New Chemical Process for Eliminating Nitrogen Oxides From Diesel Engine Exhausts**
>
> This paper introduces a new chemical process for eliminating nitrogen oxides from the exhausts of diesel engines. The process uses isocyanic acid, a nontoxic chemical used to clean swimming pools. In this paper, we show how well the process reduced emissions of nitrogen oxides from a laboratory diesel engine. To explain how the process works, we present a scheme of chemical reactions [5].

Note that the first sentence of this descriptive summary identifies the work for the audience. Do not think that the repetition between the title and summary is redundant. Being redundant is a needless repetition of details. The repetition here is purposeful—you want to clarify any doubts that the audience has about the meaning of the title. Notice also that the second sentence provides secondary details that could not fit into the title. When your title is not able to separate your work from everyone else's work, your summary has to make that separation. The final two sentences of this descriptive summary list chronologically what will occur in the document: a discussion of the experiment followed by discussion of the theory.

Because a descriptive summary does not contain the actual results, it can be written ahead of the actual paper and even ahead of the experiments or computations. In fact, many researchers write descriptive summaries to conference proceedings, even though the work is not yet finished. Another feature of a descriptive summary is conciseness, often only two or three sentences.

In actuality, most summaries are not entirely descriptive or informative. Rather, most summaries are combinations of the two:

> **New Chemical Process for Eliminating Nitrogen Oxides From Engine and Furnace Exhausts**
>
> This paper introduces a new chemical process for eliminating nitrogen oxides from engine and furnace exhausts. Nitrogen oxides are a major ingredient of smog and contribute heavily to acid rain. In our process, isocyanic acid—a nontoxic chemical used to clean swimming pools—converts the nitrogen oxides into steam, nitrogen, and other harmless gases. While other processes to reduce nitrogen oxides are expensive and, at best, only 70 percent effective, our new process is inexpensive and almost 100 percent effective.
>
> In laboratory tests, our process eliminated 99 percent of nitrogen oxides from the exhaust of a small diesel engine. If incorporated into diesel engines and industrial furnaces, this new process could greatly reduce the 21 million tons of nitrogen oxides released each year into the atmosphere of the United States. Besides presenting experimental results, this paper also presents a scheme of chemical reactions to explain how the process works [5].

Most of the sentences in this summary are informative. These sentences present the most important results: what distinguishes the new process and how effective it is at reducing nitrogen oxides from the exhaust of a test engine. The last sentence of the summary, though, is descriptive. Instead of actually presenting the scheme of chemical reactions that explain the process, the summary just states that the reactions will be given. Such a descriptive treatment was necessary because the format did not allow room for a listing of the six chemical reactions.

Many engineers and scientists find the principle of summarizing their work at the beginning difficult to swallow. They do not believe that audiences will read their papers and reports all the way through if the results are stated up front. Truth be told, these engineers and scientists are correct—many readers, after seeing a summary, will not read the entire document. However, the readers who are interested in the details of your work will continue reading. Remember: The goal of scientific writing is not to entice everyone to read to the end of your document, but to inform or persuade the intended audience as efficiently or effectively as possible.

Besides emphasizing the most important details, summaries also make it easier for audiences to read through complex documents. Not being told what is going to happen in a complex document is akin to being forced to hike a difficult trail without a map. On a hike, if you are not sure in which direction you are headed or how far you will travel, you tire more readily, especially when the trail steepens. The same is true for a challenging document. For instance, in a paper with Monte Carlo simulations, you may tire if you do not know what those simulations accomplish. If, however, you know that those simulations shed new light on specific chemical reactions that interest you, then you are more likely to stay with the paper.

## Emphasize details with placement

Where text borders white space is where you receive emphasis. Titles and headings, for instance, receive emphasis because they are surrounded by white space. In fact, the higher level the heading, the greater the white space that the artist leaves around that heading. Likewise, the beginnings and endings of sections also receive emphasis because they are bounded, either above or below, by white space. To a lesser degree, the beginnings and endings of paragraphs receive emphasis because of the white space given by the tab at the beginning of paragraphs and by the white space at the end of the paragraph's last line.

In addition, illustrations receive emphasis partly because of the white space around them, but mainly because of their appearance. Although readers might not read every sentence in a document, they almost always look at every illustration. Therefore, if you can place important results in an illustration, do so. For example, Figure 8-1 shows how much radiation the average person in the United States receives from the operation of nuclear power plants as opposed to other sources. These other sources include natural sources, such as solar radiation

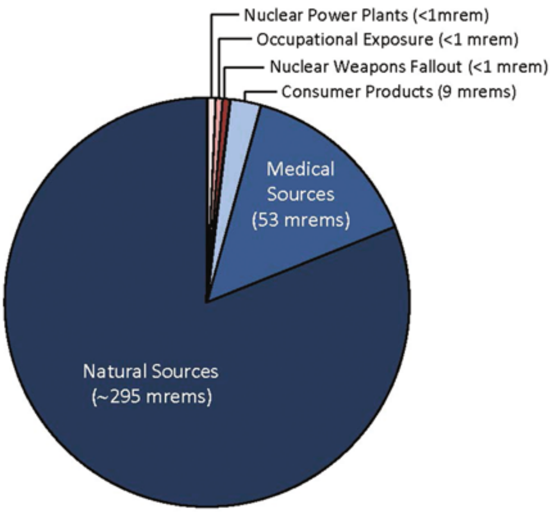


**Figure 8-1.** The breakdown of annual radiation dosage to the average person in the United States from all sources [6]. Most of the contribution comes from natural sources, such as radon and cosmic radiation.

and radon, and medical sources, such as dental X-rays. Illustrations such as Figure 8-1 stand out in papers and reports. You should realize, though, that a large number of illustrations dilutes the importance given to any one. If Figure 8-1 was one of the ten such pie graphs, it would not receive nearly as much emphasis.

In addition to using illustrations and white space for emphasis, you can also use the lengths of sentences and paragraphs. For example, a short sentence following a long sentence receives emphasis, particularly if that short sentence is the last sentence of the paragraph. Likewise, a short paragraph following a long paragraph receives emphasis. In the following example, notice how the Warren Commission used a combination of short sentences and placement at the end of the second paragraph to emphasize the name of the man in the lunchroom.

> When the shots were fired, a Dallas motorcycle patrolman, Marrion L. Baker, was riding in the motorcade at a point several cars behind the President. He had turned right from Main Street onto Houston Street and was about 200 feet south of Elm Street when he heard a shot. Baker, having recently returned from a week of deer

> hunting, was certain the shots came from a high-powered rifle. He looked up and saw pigeons scattering in the air from their perches on the Texas School Book Depository Building. He raced his motorcycle to the building, dismounted, scanned the area to the west and pushed his way through the spectators toward the entrance. There he encountered Roy Truly, the building superintendent, who offered Baker his help. They entered the building, and ran toward two elevators in the rear. Finding that both elevators were on an upper floor, they dashed up the stairs. Not more than 2 minutes had elapsed since the shooting.
>
> When they reached the second-floor landing on their way up to the top of the building, Patrolman Baker thought he caught a glimpse of someone through the small glass window in the door separating the hall area near the stairs from the small vestibule leading into the lunchroom. Gun in hand, he rushed to the door and saw a man about 20 feet away walking toward the end of the lunchroom. The man was empty-handed. At Baker's command, the man turned and approached him. Truly, who had started up the stairs to the third floor ahead of Baker, returned to see what had delayed the patrolman. Baker asked Truly whether he knew the man in the lunchroom. Truly replied that the man worked in the building, whereupon Baker turned from the man and proceeded, with Truly, up the stairs. The man they encountered had started working in the Texas School Book Depository Building on October 16, 1963. His fellow workers described him as very quiet—a "loner." His name was Lee Harvey Oswald [7].

Placement can work in the opposite way: Placing important information in the wrong place can greatly reduce the chances that the audience will remember that information. For instance, many scientists and engineers bury details in long lists:

> This report uses data from both the test and evaluation and power production phases to evaluate the performance of the Solar One receiver. Receiver performance includes such receiver characteristics as point-in-time steady state efficiency, average efficiency, start-up time, operation time, operations during cloud transients, panel mechanical supports, and tube leaks. Each of these characteristics will be covered in some detail in this report.

Now that you have read this paragraph, close your eyes and name as many receiver characteristics as you can that will be covered in the report. Did you remember all seven items? As stated earlier, people remember things in groups of twos, threes, and fours. The list here was too long. Also, a problem was that the list occurred in the middle of the paragraph. A better way to emphasize this information would be to group those characteristics and then place the list in a location, perhaps the end of the paragraph, that receives more emphasis.

> This report uses data from both the test and production phases to evaluate the performance of the Solar One receiver. In this report, we will evaluate performance by studying the receiver's efficiency, operation cycle, and mechanical wear.

You might ask why not format the list vertically down the page. Because of the additional white space, this vertical list would certainly receive more emphasis. The main reason is that although vertical lists serve instructions and résumés, too many vertical lists disrupt the reading of papers and reports. These disruptions in reading occur much in the same way that traffic lights slow the driving through a city. If the list is truly important and one that the readers would search for, such as work tasks in an email or research hypotheses in a thesis, you might format it vertically. However, if you have more than one vertical list for every two or three pages of text, you should reconsider. While frequent vertical lists often serve a resume or set of instructions, too many vertical lists make a paper, report, or proposal appear like an outline.

An alternative to a vertical list is a table. Tables are not just for numbers. Skilled writers also incorporate columns of short, parallel descriptions. One way to view a table is as a matrix of information. While a vertical list gives only one perspective to a topic, a table can give two, three, or more perspectives.

Vertical lists, particularly when they are long, are notorious for burying information. The following was a list of recommendations from Morton Thiokol to NASA on improvements needed for the solid rocket booster of the space shuttle. The list came from a briefing that preceded the Space Shuttle Challenger disaster by over 5 months. Because the list was long, the emphasis given to the first recommendation was diluted [8].

**Recommendations**

- The lack of a good secondary seal in the field joint is most critical and ways to reduce joint rotation should be incorporated as soon as possible to reduce criticality.
- The flow conditions in the joint areas during ignition and motor operation need to be established through cold flow modeling to eliminate O-ring erosion.
- QM-5 static test should be used to qualify a second source of the only flight certified joint filler material to protect the flight program schedule.
- VLS-1 should use the only flight certified joint filler material in all joints.
- Additional hot and cold subscale tests need to be conducted to improve analytical modeling of O-ring erosion problem.
- Analysis of existing data indicates that it is safe to continue flying existing design as long as all joints are leak checked with a 200 psig stabilization pressure, are free of contamination in seal areas and meet O-ring squeeze requirements.
- Efforts need to continue at an accelerated pace to eliminate SRM seal erosion.

In addition to noting that the list was too long, Richard Feynman pointed out that a contradiction exists between the sixth item and the first [9].

How could the important details of this list be better emphasized? One improvement would have been to make a short list of the two or three most important recommendations followed by a list of the secondary recommendations on a separate page. Another improvement would have been to rework the language. The sentences are full of imprecision and needless complexity. For instance, in the first recommendation, what did the writer mean by the phrase "most critical"? No middle ground exists with the word *critical*. Something is either critical or not. Other problems with the language include wordiness, discontinuities, and needless passive voice.

Finally, the author should rethink the use of bullets. Although bullets are a pet stylistic device for many engineers and scientists, the purpose of bullets is to remove hierarchy. Unfortunately, removing hierarchy also removes emphasis. A better choice is a numbered list, which at least provides an order. Another reason to challenge bullets is that they do not show connections [10], and connections are important for a reader's understanding, especially when the information is complex. Yet a third reason to challenge bullet lists is that they are first-draft thinking. Perhaps many engineers and scientists like bullet lists because they are easy to write, but for an author attempting to persuade or for a reader seeking to understand, bullet lists fail to deliver. Richard Feynman challenged their value in scientific writing [9], and so do I.

## Move larger blocks of secondary information into appendices

So far, this lesson has discussed how to increase emphasis. Do occasions exist in which you want to reduce emphasis? The answer is yes. For instance, you typically write reports for two or three types of readers, with each type having a different technical background and reason for reading the report. Given that, how do you write the main text of your report for all these audiences? The answer is that you do not. Instead, you place the primary information for your primary audience in the ***main text*** of the report, and then you use ***appendices*** for secondary types of information.

Note that the length of the information affects your decision whether to create an appendix. In general, you can think of secondary information as a branch that takes readers away from the main trunk of the report. If the branch is long (more one page), placing that information into an appendix generally serves the report. However, if the tangent is only a paragraph or two, then an appendix generally does not serve.

One common type of appendix presents background information to help a less technical audience understand the report. For example, if you had written a report on improving a chemical test for the forensic analysis of blood, you might include an appendix for less technical readers that explains how bloodstains are analyzed. As with any appendix, this appendix should stand on its own as a separate document with a beginning, middle, and ending.

A second common type of appendix provides information that would be too detailed for the main story of the report. For instance, while the text of a report might include curves representing the results of an experiment, an appendix might include the raw experimental data that you used to create those curves. In doing so, the report allows an audience member the chance to challenge the calculations and assumptions behind the curves.

Still, a third kind of appendix is the one that provides information which is tangential to the focus of the report, but interesting for readers. For a report on forensic techniques, such information might be a case study of the Birmingham Six. In this case, six men were wrongly convicted of bombing two pubs in Birmingham, England. The men were convicted on the basis of a single test, called the Greiss Test, which detected amounts of nitroglycerine. The men tested positive. Years later, while researching the Greiss test, scientists discovered that contact with many substances such as playing cards, adhesive tape, and plastic wrappers from cigarette packages produced false positives [11]. Although information about this case of the Birmingham Six might not be necessary for understanding the work, you still might include the information for the sake of completeness or audience interest. In such a situation, an appendix would be an appropriate place for the information.

For proper transitions, you should mention each appendix at least one time in the document before that appendix appears. In other words, when the connection to the information arises in the text, refer readers to the appropriate appendix.

> The mass spectrometer must also be in a high vacuum to minimize the number of gas molecules that collide with the ions. For more information on the different types of mass spectrometers, see Appendix E.

A glossary is a special appendix that provides definitions to secondary audiences. For instance, consider a report on the effects of spaceflight on the human immune system in which immunologists are the primary audience and NASA management makes up a secondary audience. In the back of the report, the author might include the following glossary to help NASA management navigate the immunology terms [12].

### Glossary

**antibody:** a protein molecule that is released by a daughter cell of an activated B cell. Antibodies bind with antigens and serve as markers that give signals to immune cells capable of destroying the antigens.

**antigen:** a substance or part of a substance that is recognized as foreign by the immune system, activates the immune system, and reacts with immune cells and their products.

**cytoxic:** a type of activity related to destructive capabilities. The word *cytoxic* can be used interchangeably with the word *killing*.

**humoral:** of or pertaining to body fluids.

**immune response:** a defensive response by the immune system as a reaction to detection of an antigen. T cells and B cells detect antigens after the macrophage has signaled that an antigen is present. This detection by the T cells and B cells provokes the cells to respond; thus, they become activated.

**immunocompetent:** ability of the body's immune cells to recognize specific antigens. When T cells and B cells become immunocompetent, they are able to attack antigens.

**immunodeficiency:** a disease resulting from the deficient production or function of immune cells required for normal immunity.

**killer T cell:** a type of T cell that directly kills foreign cells, cancer cells, or virus-infected body cells.

**white blood cell:** a type of body cell that is involved in body protection and takes part in the immune response. For instance, lymphocytes are a specific type of white blood cell

This glossary allows the author to inform the secondary readers about the vocabulary of the report without breaking the continuity of the writing for the primary readers. Notice that if the primary readers had been NASA management, it would have been appropriate to define these terms in the text. Notice also that even if the author defines a term in the text, the author still might include the term in the glossary, especially if the document is long and the term appears in several sections.

In creating a glossary, arrange terms in alphabetical order. Also, the first time that the term is used in the text, you should use a typographical feature, such as italics, to signal readers that the glossary will define that term. As with appendices, the glossary should have a direct connection to the text of the document—for instance, a parenthetical statement after the first italicized term saying that "all terms in italics are defined in the Glossary."

Documents such as brochures and popular journals often have box stories, also called "sidebars," that fill the same role as appendices and glossaries in a report. Instead of falling at the end of the document, these box stories are formatted alongside the text so that a secondary audience can stop and read them. In practice, some documents have so many box stories that primary audiences need a map to figure out the next paragraph of the main text. In such cases, the writer has sacrificed the primary audience's continuity in reading for the chance to give background or detour information to the secondary audience—not a good trade.

The hypertext of the World Wide Web overcomes this problem by placing the secondary information (appendices, box stories, and glossary definitions) in hidden computer windows. The readers then have a choice: continue reading the text or access the window by clicking on a color-coded word or phrase. In essence, what hypertext provides is an efficient way for secondary readers to reach the back matter without interrupting the main text for the primary readers.

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Lesson 9

# Adapting Your Style to Emails, Instructions, and Proposals

*The goals of my research are to uncover the genes that are mutated in Tasmanian devil cancer. However, when I started this research, I did not simply throw on a lab coat and head for the lab. Before I could start anything, I needed to write proposals to persuade funding bodies that their money would be well spent supporting my research.*

—Elizabeth Murchison

So far, this book has focused on scientific papers and reports. What about other types of documents? In engineering and science, a host of different documents exists with a wide range of lengths—from one-page letters applying for jobs to multi-volume tomes assessing contamination for a site's air, water, and soil. In addition, documents in scientific writing vary widely in the style—from the cohesive paragraphs of a white paper to the itemized lists in a set of specifications. In the end, though, how you write each document depends on your analysis of the audience, purpose, and occasion. Nonetheless, three types of documents are so prevalent in engineering and science that they warrant special discussion: emails, instructions, and proposals.


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_9

## An effective email is a balance between *I* and *you*

Emails, which engineers and scientists write more often than any other type of document, are an effective way to make requests and deliver specific information. Unlike a telephone conversation, an email presents the audience with a contract that is dated and can support a claim in court. Besides the advantage of legality, an email has the advantage of efficiency when you want to reach several people. In short, writing a single email will take you much less time than phoning 25 people. Also, when a message is challenging to phrase, such as requesting an extension on a due date, writing an email allows you the advantage of revising the message until it is correct. Finally, the process of writing, sending, and receiving an email can occur in a matter of minutes.

When the situation is straightforward, such as the announcement of a meeting, the email simply entails that you state the purpose, present the desired information, and then close. When the situation is not straightforward, you should first consider whether email is the appropriate form of communication. Too often, engineers and scientists will attempt an email, when a better means of communication exists. For instance, emails are not efficient at setting up a meeting date among several people. In this case, an online poll works better. Likewise, an email is not effective for negotiating the specifics of a contract. In this situation, a phone call is more effective. Finally, an email is not the way to address a conflict that you have with a colleague. Trying to resolve a conflict with email can easily erupt into “flame-mail” exchanges that could embarrass you when the other party forwards one of your heated responses up through management. Although uncomfortable, face-to-face meetings are usually best for resolving conflicts among colleagues.

**Analyzing Audience, Purpose, and Occasion.** As with any document, you should analyze the audience, purpose, and occasion of your emails. On the surface, the analysis of audience in writing emails is straightforward. Whereas reports typically have two or more distinct audiences, emails usually target only one type of audience. Still, the two most important concerns for the audience of an email are what the audience knows about the subject and why the audience is reading. Your thinking on the first of these concerns for emails is similar to your thinking for papers and reports. In other words, how much the audience knows about the subject dictates what background information you present and which words you define.

The second concern about why the audience will read the email depends on the occasion. For instance, for an email that supplies a requested recommendation, the recipient of the email has already established the reason for the correspondence. Therefore, as long as your email clearly states the purpose at the beginning, the recipient is a willing reader.

With most emails, though, the question of why the audience reads the email is often answered in two parts: (1) why the audience begins reading the email and (2) why the audience continues reading. Audiences begin reading an email for the simple reason that the email is in their inbox. Part of the motivation is obligation to professional duty; another part is curiosity. As for why the audience continues reading the email, much depends on who the author is. If you have much credibility with the audience, the audience will read your email. Otherwise, whether they continue reading depends on your beginning.

In crafting the beginning of an email, you should keep a third concern about audience in mind—namely, how the audience reads an email. People do not read emails in the same way that they read a novel: sitting in an easy chair and drinking a cup of tea. Instead, when reading an email, your audience likely has a finger poised on the delete button. Most of us confront a long list of emails each day, and we delight in discarding as many as possible just by viewing the list of senders and subject lines. Because readers have your email in such a precarious position, the subject line is critical.

Speed is another consideration for how people read emails. Emails are read more quickly than are papers or reports. If the reading speed of papers and reports were a steady jog, then the reading speed for emails would be a sprint. For that reason, having emails go longer than what the computer screen displays can intimidate readers. After all, readers can sprint for only so long. Although occasions arise in which the scope of the email requires significant length, you should strive to have your emails to fit onto the computer screen's display.

Purpose is yet another consideration for emails. While all emails in science and engineering are informative, the amount of persuasion in different types of emails ranges as shown in Figure 9-1 from almost none (a meeting announcement) to much (a request for a change). Certainly, for each of these types of email, a range of persuasion exists, but the markers in the figure represent a typical distribution.

As with the writing style of papers and reports, the style of an email is greatly affected by the amount of persuasion. In general, the more persuasive the email is, the longer the sentences and paragraphs are. Why is that? In a meeting announcement, which has little to no persuasion, you focus on the *who*, *what*, *when*, and *where*. However, in a request for a change, which has a high level of persuasion, you also give the

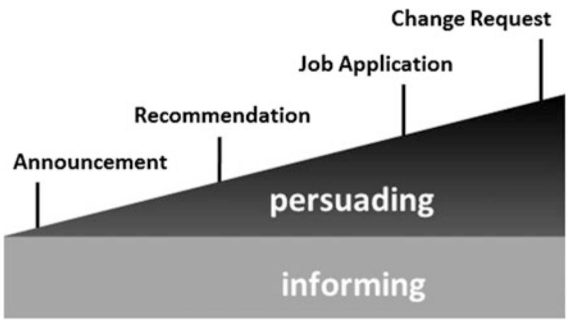


**Figure 9-1.** Representation of the amount of persuasion needed for four common types of emails: an email announcement, an email that recommends someone for a position, an email applying for a job, and an email that requests a change within an organization.

*why*. As discussed in Lessons 5 and 8, from a sentence perspective, being persuasive calls on you to include dependent clauses and infinitive phrases that answer the question *why*. These additions significantly lengthen the sentences. From a paragraph perspective, when persuading, you spend sentences making bridges to the opposing view, building your credibility, and refuting counterarguments. Such expenditures significantly lengthen paragraphs.

In emails, two aspects of occasion have much importance. One is the format, which as already defined is the arrangement of type on the page. Although no universal format exists for professional emails, some format decisions are almost universal—at least, for emails written in English. For instance, in a professional email in which you are contacting someone for the first time, the expectation is that you place a colon (or em-dash), rather than a comma, after the greeting. Although seemingly small, using a colon is a sign of respect, similar to greeting a senior colleague in German with *Sie* as opposed to *du*. Another format expectation that is almost universal is to insert vertical space between paragraphs—an expectation that does not exist in articles or reports.

In addition to format, the mechanical rules for grammar, punctuation, usage, and spelling are an important consideration for emails. One reason for this increased importance on mechanics is the brevity of emails. In effect, a mechanical error such as a misspelling in a one-page email receives more attention than the same error in the middle of a 50-page report. While a misspelling on your part during an email flurry to colleagues is no cause for alarm, the same misspelling in an email (or letter) applying for a job is. Employers who face a stack of job applications look for quick ways to reduce the stack, and finding mechanical errors in the applications is a common means for doing so.

To eliminate mechanical errors for such important pieces of correspondence, a good idea is to let the email cool before making the final proof. Better still, for your most important emails, let the email sit overnight and then proofread a printed version the first thing in the morning. Not only will you be in a better position to catch the difficult errors, such as a missing or repeated word, but you will be better able to evaluate the email's ***tone***, which is the attitude of the writer toward the subject. For instance, an adverb such as "frankly," which might seem appropriate at the end of a long afternoon, might sound harsh at eight o'clock the next morning.

**Structure.** Although emails are short, you should still think of emails as having a beginning, middle, and ending. The beginning of an email should orient the audience, the middle should deliver the message, and the ending should provide or suggest the next step.

As mentioned, when plowing through a stack of emails, readers often have a finger on the delete button. Given that, in writing an email, you want to orient your readers as quickly as possible to what the email contains. That orientation means getting to the point in the subject line. In the heat of battle, many engineers and scientists simply dash off a one- or two-word subject line written from their own perspective:

**Subject:** Tumor Purity

Such a subject line is a missed opportunity to orient the reader to the perspective on the project. Even when the audience is familiar with the project being discussed, you should craft a title that gives the email's perspective on that project:

**Subject:** Adjusting for Differences in Purity of Cancerous Tumors

One reason for providing the perspective in the title is that the reader can assess more readily the importance of the email. Second, because the title of an email becomes repeated in email responses, a vague title such as "Tumor Purity" can propagate multiple times and be forwarded to additional readers. Third, readers often search through older emails to recover specific details. When viewed months later, a title such as "Tumor Purity" likely does not distinguish this email from other similar email titles that could also contain the desired information.

Just as subject lines of emails should orient, so should the first paragraphs of emails. For instance, the first sentence of the first paragraph often clarifies the purpose of the email and the remainder of the paragraph establishes credibility and previews the structure. The following email, which applies for an internship, uses that structure:

> Dear Dr. Patzer:
>
> Please consider me for a summer internship position with your mechanical design department. I am a junior at Pennsylvania State University pursing a bachelor of science in mechanical engineering. For the past few years, I have had an interest in engineering design as applied to the musical and theatrical industries and have applied that interest to my course work and extracurricular activities [2].

As would be expected, this email had additional paragraphs: one that discussed the author's course work, another which discussed her extracurricular activities, and a final paragraph that provided a conclusion.

In some correspondence, you would do better to place a sentence or two of background information before the sentence that states the purpose of the correspondence. Nonetheless, you should state the purpose in the first paragraph. For example, consider the subject line and first paragraph of the following email [3], which was written by a graduate student to her research advisors:

> **Subject:** Possible Seed Particle for LDV Measurements
> in the Wind Tunnel
>
> As you know, for the past six months, we have been unable to make simultaneous Laser Doppler Velocimetry (LDV) and hot-wire measurements of velocity in the wind tunnel because our LDV seed has contaminated the hot wire. Titanium dioxide, the seed particle that we use, changes the hot-wire measurement of velocity by as much as 17 percent over a 40-minute period. This email presents the results of my search to find a LDV seed particle that does not contaminate the hot wire [3].

In this email, having the scope stated in the subject line allowed the author to give two background sentences before stating the email's purpose. Not only did this opening paragraph orient the advisors at the time, but the opening would have also oriented the advisors months later.

The middle in the correspondence either delivers the information or makes the argument. In most correspondence, that delivery translates to writing one or more paragraphs that present what was promised or proposed in the beginning.

> After unsuccessfully trying other seed particles such as alumina and silicon carbide, I received an idea from Professor Jim Wallace of the University of Maryland. Professor Wallace uses incense to perform smoke visualization studies while simultaneously making measurements with a hot wire. Even though Professor Wallace needs a dense smoke for the flow visualization, he claims that his hot wires are not contaminated by the tar particles contained in the incense.
>
> Professor Wallace's smoke generator includes a steel wool filter to collect the tar particles. This generator also cools the smoke to prevent temperature fluctuations from affecting the hot-wire measurements. The smoke is cooled by simply sending the smoke through an air-cooled copper coil before injecting it into the wind tunnel [3].

Often, in persuasive emails such as an application for a job, the first sentence of the paragraph states an assertion or claim, and the remaining sentences provide evidence of support, such as statistics, examples, or a reference to a résumé.

The email ending, which usually encompasses the final sentence or paragraph of the correspondence, can go in several directions. In an email that primarily informs, the ending typically presents a summary of the information. In an email that both informs and persuades, the ending often presents a call for action, in which you state what you want the audience to do. Sometimes, that call for action is loud, as in this closing to an email proposing a course of action: "With your approval, I will begin these experiments." Other times, the call is subtle, as in this closing to an email that applies for an internship: "Thank you for your consideration." Consider the following final paragraph to the email proposing a new seed particle for velocity measurements in a wind tunnel:

> After this discussion with Professor Wallace, I began testing incense and found that it was an acceptable LDV seed. The steel wool, when used with the air-cooled copper coil, works as an acceptable filter for the tar particles. From this research, I recommend that we use incense as the seed particle for our simultaneous measurements of velocity using the hot wire and the LDV [3].

**Language.** Although some engineers and scientists are uncomfortable using *I* or *we* in a paper or report, no such taboos exist with emails. In many ways, writing an email is akin to sitting across the desk from the reader and giving your side of a professional conversation. Although the first person is universally accepted in emails, the entire conversation should not center on *I*, as this prospective graduate student did:

> I am interested in obtaining a research position in a gas turbine lab. I am finishing my bachelor of science in mechanical engineering this May. I have also had summer internships at General Electric Aviation and at Boeing.

Although the student appears to be qualified to work in a gas turbine laboratory, this paragraph is not nearly as strong as it could be because the conversation is so one-sided. Part of that one-sided appearance arises because the author frequently uses *I*, but does not use *you*. In addition, the author emphasizes *I* by beginning each sentence with this pronoun.

A more thoughtful writer would think about connections to the reader (*you*) and would work those into the conversation:

> Working in your laboratory interests me because currently I am employed by one of your research sponsors: Pratt & Whitney. In particular, your experiments concerning the effects of sand on turbine components, as described on your website, particularly appeal to me because through family members in the military, I have learned about the negative effects that sand can have on aircraft engines.

Although this application email was for the same laboratory as was the weak application email above, this second writer succeeded, in part because he balanced the number of times that he wrote *I* with the number of times that he wrote *you*.

**Tone.** Tone is whatever in the writing shows your attitude toward the subject. In emails, tone is difficult to control. Why? One reason is that more than any other type of document, an email is a conversation between the writer and the reader. Often, these conversations are challenging. For instance, how in a job application email (or letter) do you talk about your accomplishments without sounding boastful? Also, in an email complaining about shoddy workmanship, how do you motivate the reader to address the problems? These answers are not simple.

Often, engineers and scientists lose control of tone by avoiding simple, straightforward wording. When some people sit down to write an email or letter, they change their personalities. For instance, instead of using normal English, many engineers and scientists use stilted phrases such as "per your request" and "enclosed please find." Because these phrases are not straightforward, they inject an undesired attitude—often arrogance—into the writing. Other times, engineers and scientists adopt ***clichés*** that make the writing silly. Neither of these traits are desirable for your writing.

Many times, to be precise in scientific writing, engineers and scientists have to use long words. Because words such as "polystyrene" and "glycosuria" have no simple substitutes, they are precise for many instances. However, many long words used in scientific writing are needlessly unfamiliar. Words such as "facilitate" and "implementation" are pretentious. As stated in earlier lessons, these words offer no precision or clarity to the writing. Worse yet, they smack of a pseudo-intellectuality that poses a barrier between writer and reader. Below is a short list of common pretentious words from scientific writing:

approximately: appropriate when used to modify a measurement's accuracy to within a fraction, but pretentious when applied to a rougher estimation such as "approximately ten people." Does the writer mean 9.75 or 10.25 people? In such cases, use the simple word *about*.

component: often can be replaced by *part*.

facilitate: a bureaucrat's word. Instead, select simpler wording such as *help*, *cause*, *bring about*, or perhaps *foster*.

manufacturability: a pretentious way to say "can manufacture." You should challenge *-ability* words—their presence usually indicates that the sentence should be rewritten with a stronger verb preceded by the word *can*.

prioritize: a pretentious way to say the verb *rank*. You should challenge *-ize* verbs, because many times, a simpler substitute exists.

utilization: a pretentious way to say the noun *use.* You should challenge *-ization* nouns.

Many of these words are long, most of these words are recent creations, and all of these words have infested scientific writing. What these kinds of words do is to hide the meaning, as in this sentence from an email written by a chemist:

> The elevated temperatures of the liquid propellant fuel facilitated an unscheduled irrevocable disassembly.

What actually occurred was straightforward:

> The higher temperatures caused the liquid propellant to explode.

Besides using pretentious words, many scientists and engineers lose control of tone by choosing arrogant phrases, such as in these two sentences from a journal article:

> As is well known, the use of gaseous insulation is becoming increasingly more widespread, with gases such as air and sulfur hexafluoride featuring prominently. There has been some discussion of using gas mixtures like nitrogen and sulfur hexafluoride, and of course nitrogen is the major constituent of air.

Besides problems with precision and clarity, these two sentences have problems with tone. The phrase "as is well known" is not forthright. If the readers know (and know well) the particular detail about gaseous insulation, why does the writer mention it? However, if the readers do not know the detail, as is probably the case, then the writer has assumed a superior position over the reader. The phrase "of course" in the second sentence strikes the same chord.

Another arrogant phrase often found in scientific writing is "clearly demonstrate."

> The results clearly demonstrate the ability of Raman spectroscopy to provide unambiguous chemical compound identifications from oxides as they grow on a metal surface.

When someone uses "clearly demonstrate" to describe a result or illustration, more often than not that result or illustration does not "clearly demonstrate" anything at all. Therefore, readers are left wondering if the writer is trying to hide something. The word *unambiguous* in the same example is also arrogant; it defies the reader to question the work. A forthright revision would be

> The results show that Raman spectroscopy can identify chemical compounds from oxides that are growing on a metal surface.

The revision is simple and straightforward. Scientific work should stand on its own merit without cajoling from the writer.

Perhaps the most arrogant expression in scientific writing is the phrase "it is obvious." If the detail is obvious, then you should not include it, and if the detail is not obvious, as is usually the case, calling the detail obvious will serve only to annoy your readers. Many insecure engineers and scientists hide behind these arrogant phrases. These engineers and scientists think—subconsciously, perhaps—that the arrogant phrases will ward off challenges to their work. If anything, these phrases invite rebuttal.

Besides relying on pretentious words or arrogant phrases, other engineers and scientists lose control of tone by injecting a silliness into their writing. The most common source of this silliness arises is through using clichés, which are figurative expressions that have become too familiar. These expressions were once fresh in writing, but through overuse, have taken on undesirable connotations. Consider the following sentence from an email at a national laboratory:

> When you come up to speed, I will touch base with you and we'll knock heads together to figure out a solution!

"Come up to speed," "touch base with you," "knock heads together"—these phrases are overused to the point of sounding cute. The exclamation point also falls into this category. So many books in primary school have used the exclamation point for emphasis that this piece of punctuation does not emphasize anymore. Rather, the exclamation point conjures memories of primary school books.

Because the exclamation point is often used on congratulatory greeting cards, this piece of punctuation raises expectations for the reader, even when those expectations should be dampened. Recently, a colleague of mine made it to the final candidate grouping for a prestigious dean of engineering position. After the interviews, the colleague received an email from someone on the search committee requesting a phone call with the institution's provost. Because the email had two exclamation points (one after the greeting and the other in the salutation), the colleague was optimistic about the phone call. However, the call stunned the candidate with the news that the institution selected another candidate. The takeaway here is to avoid exclamation points in professional writing.

Clichés abound in the emails and letters of some engineers and scientists. Consider the following short paragraph from a job application letter (by the way, the ellipsis at the end was part of the original paragraph):

> I am in search of a meaningful growth position, and your company is a gateway to the highest professional levels and beyond…

The clichés in this sentence are imprecise and unclear. The phrase "meaningful growth position" is open to several interpretations, the word "gateway" suggests that the writer wants a job in a port city such as St. Louis, and the phrase "and beyond" followed by an ellipsis ("…") conjures an opening to a space adventure movie. While the ellipsis is appropriate when you are indicating something missing from a quotation, it has become a cliché when used as a pointed finger to the future.

How do you know whether a descriptive phrase is a cliché? If you have heard the descriptive phrase several times before ("sticks out like a sore thumb") or if it strikes a high-pitched chord that makes you cringe ("greatest thing since sliced bread"), then it is likely a cliché.

## Instructions rely on numbered lists

Put simply, instructions teach audiences how to perform a process. Instructions range in length from a manual for a software program to a label for handling a toxic chemical. Both of these examples point to the importance of well-written instructions. If the software manual is disorganized, users of the program will waste time searching for commands. If the safety label for handling the toxic chemical is ambiguous, someone might become ill. Money, time, and health depend on the quality of the writing in instructions.

**Audience, Purpose, and Occasion.** Unlike a paper or report, in which the audience is interested in both the *how* and the *why*, instructions are written for audiences who focus on the single-minded, often impatient, question of *how*. For that reason, in organizing a set of instructions, you should anticipate the information that the reader desires and make that information easy to locate. For instance, because readers of a software manual often search for single commands, you should provide a detailed table of contents and perhaps an index to help readers find those commands. For detailed instructions on handling a toxic chemical, you should include medical procedures on what to do in the case someone ingests that chemical.

The one exception to helping readers quickly find the desired information occurs when a difficult or dangerous step stands between the reader and that information. In such a case, you want to insure that the search for the information passes through the caution for that difficult or difficult step. Often, that insurance entails placing the caution in glaring, not-to-be-missed typography.

Examining how an audience reads a set of instructions reveals why instructions have such an unusual style and such varied formats. As with reading correspondence, when reading instructions, audiences rarely sit in soft chairs by fireplaces. Rather, they often try to perform the process as they are reading the instructions. For that reason, the formats for instructions are tailored to make it easier for the audience to read and work simultaneously. For instance, formats for instructions often call for section headings to be numbered (for instance, Section 2.1.4) to indicate the position and hierarchy of that section. Although this notation adds complexity to the look of the document, the notation serves instruction manuals because of the speed with which the audience can locate the desired information. For instance, Section 2.1.4 refers to the fourth sub-subsection of the first subsection of the document's second section. Note that for documents where the audience is not jumping from one section to another, you should avoid this added complexity.

Besides having numbered sections, formats for instructions often contain unusual typography. For instance, in the middle of instructions, you are likely to see special typography containing a caution:

**Caution: A drugged hippopotamus still cannot be handled safely.**

Moreover, the layouts of instructions do not look like the layouts of other documents. On average, instructions have a greater percentage of space dedicated to illustrations than do other documents. For instance, when reading an owner's manual, you sometimes see the text supporting the illustrations, as opposed to illustrations supporting the text. Layouts for instructions also have more white space than other documents. This additional white space arises from the numbered lists, cautions, and additional illustrations.

**Organization.** At the heart of a set of instructions are the steps of the process. The beginning prepares the audience to perform this process. In turn, the middle presents those steps. Finally, the ending looks back on the process to summarize the process and provide a perspective once the audience has performed the process. The following is a title and table of contents outline for a sample set of instructions [4].

**How to Capture a Hippopotamus in the Wild**

**Summary**

**Introduction**

Hippopotamus: Characteristics and Domain
Needed Personnel and Equipment
Precautions
  For Personnel
  For Hippopotami
Strategies for Capture

**Step-by-Step Instructions**

Physical Capture
  Preparing the Enclosure
  Luring a Hippopotamus into the Enclosure
  Loading the Captured Hippopotamus

Chemical Capture
  Preparing the Enclosure
  Drugging the Hippopotamus
  Handling the Drugged Hippopotamus
  Loading the Drugged Hippopotamus

**Conclusion**

**Appendix A: Transporting a Hippopotamus**

**Appendix B: Veterinary Procedures for a Hippopotamus**

**Index**

***Beginning.*** In a set of instructions, the beginning, which prepares readers to perform the process, often includes a title, summary, and introduction. In the title, you want to do two things: (1) indicate that the document is a set of instructions, and (2) indicate what process the document will explain. To accomplish the first task, you can format the title as a participial phrase ("Using a Hot-Wire Probe") or you can use key words such as "Instructions for" or "How to" (as in the hippopotamus example). To accomplish the second task, you can simply include the name of the process: "Preparing for an Earthquake" or "How to Locate Metal Fatigue in an Airplane Wing."

For a set of instructions such as the example on capturing a hippopotamus in the wild, the summary is typically descriptive rather than informative. The reason is that because an informative summary of a process would be essentially the step-by-step instructions, this type of summary would be too difficult or dangerous to state for many processes. In such a summary, the audience would read the steps of the process without reading the background that explains those steps or the cautions that precede those steps. Given that, the summary for a set of instructions is typically descriptive (essentially a table of contents in paragraph form):

> **Summary.** These instructions, which are for professional guides and trackers in Africa, explain how to capture a hippopotamus in the wild. The purposes of such captures are two-fold: (1) to remove hippos that pose a threat to human populations, and (2) to transport endangered hippos to areas that are safer for the beasts. These instructions explain two types of strategies: physical capture and chemical capture.

The introduction to a set of instructions answers explicitly or implicitly four questions that readers expect to have answered before they reach the step-by-step instructions: (1) what the process is, (2) why the process is important, (3) who or what is needed to perform the process, and (4) how the process will be explained. In some instances, you might not have to answer all of the questions explicitly, because the audience already knows the answer. Also, as with introductions for other types of documents, the order in which these questions are answered depends on the content and the audience.

In the outline for the hippopotamus instructions, the first section (Hippopotamus: Characteristics and Terrain) answers the first and second questions on what the process is and why it is important. In addition, the second section (Needed Personnel and Equipment) and third section (Precautions) address the third question on who or what is needed to perform the process. Finally, the fourth section (Strategies for Capture) addresses the fourth question by providing a mapping of the two strategies: physical capture and chemical capture.

***Middle.*** In the middle of a set of instructions, you present the information needed to perform the process. Some processes, such as changing a tire, lend themselves to a single step-by-step explanation. Other processes, such as running a computer program, involve multiple series of steps: some performed by all readers, but many others performed by only a portion of the readers. Whatever the process, the organization should not only be logical but also be clear. A chronological order is the most common. In such an explanation, you start at the beginning of the process and continue through to its end. Some processes, such as using a spreadsheet computer program, do not lend themselves to step-by-step chronology. In those instances, you divide the process into logical sections and subsections.

As shown in the outline for capturing a hippopotamus in the wild, the author presented two strategies for capturing a hippopotamus: physical capture and chemical capture. Each strategy was divided into sections that followed chronological strategies.

***Ending.*** The ending to a set of instructions usually does two things: (1) summarizes the process by showing the interrelation of steps, and (2) gives a future perspective once the audience has performed the process. Unlike the instruction set's initial summary, the summary in the conclusion addresses an audience who has already read the instructions (including the cautions). This summary, therefore, can take more liberties than the initial summary, which as mentioned is usually descriptive.

The second goal that an ending to a set of instructions has is to give a future perspective to someone who has performed the process. In an instructional brochure on how to operate a streak camera, that perspective might be a troubleshooting guide. That future perspective might also include information on obtaining replacement parts. In the hippopotamus example, the two appendices present procedures that arise after the capture process has occurred: transporting a hippopotamus and treating a hippopotamus in case of injury or illness.

**Language.** When audiences read instructions, they often try to perform the process. To serve this situation, the language of instructions has three distinct traits: (1) the use of numbered steps, (2) direct addressing of the audience with the pronoun *you*, and (3) a succinct style with notably shorter sentences and paragraphs.

As an example, given below are the first two steps for a subsection of the instructions to capture a wild hippopotamus [4].

**Handling the Drugged Hippo**

1. *Wait until the hippopotamus is recumbent.* A high-stepping gait indicates that the drug is taking effect. Note: A drugged hippopotamus still cannot be handled safely. Later, the animal sits and stands repeatedly before the forelegs collapse and it lies on its sternum. Full immobilization may take an hour.
2. *Approach from the rear and stand against the side of the animal.* Although the hippopotamus is recumbent, its head remains active, and the animal can bite. Standing against the animal's side keeps you out of the mouth's reach.

In these two steps, the first sentence, which is the actual step, appears in italics to distinguish it from the step's explanation.

As opposed to relying solely on traditional paragraphs, instructions often use on numbered lists that are arranged vertically, with each item separated by white space. Although such lists would make the reading of a research paper or formal report choppy, these lists serve instructions because the audience can read the step and then turn away from the page and perform the step. The numbers and the white space allow the readers to find their places.

For each section of a set of instructions, you should try limiting the number of steps to two, three, or four. Long lists can overwhelm an audience. For complicated procedures, use subsections to divide longer processes into manageable lists. As an example, consider again the subsections for the two ways to capture a hippopotamus in the wild:

Physical Capture
- Preparing the Enclosure
- Luring a Hippopotamus into the Enclosure
- Loading the Captured Hippopotamus

Chemical Capture
- Preparing the Enclosure
- Drugging the Hippopotamus
- Handling the Drugged Hippopotamus
- Loading the Drugged Hippopotamus

Unlike research articles and formal reports, instructions often include sentences written in the second person (*you*). The reason is that with instructions the audience is a part of the process. Moreover, as shown in the two steps from the hippopotamus example, instructions include sentences written in the ***imperative mood***. For example, although the word *you* does not appear in the sentence stating the second step, *you* is implicitly the subject of the sentence: "*Approach from the rear and stand against the side of the animal*." Often in instructions, you restrict the use of the imperative mood to cautions and sentences presenting the actual steps.

In general, the language of scientific writing is a balance among several goals—being precise, clear, familiar, energetic, and connected. With instructions, because the audience is often performing the process while reading, the goal of being clear receives even more emphasis than in other documents. In particular, instructions demand that you not have any ambiguities, especially those that could lead to mistakes or injuries.

The increased emphasis on being clear in instructions can be seen in the average lengths of sentences and paragraphs. Typically, instructions have shorter sentences and paragraphs than those occurring in research articles and formal reports. As stated, one reason is that the author focuses on the *how* of the process, rather than the *why.* Leaving out the *why* of paragraphs reduces the number of sentences. Likewise, leaving out the *why* of sentences—the infinitive phrases and certain dependent clauses—shortens the sentences that remain. An exception would be when you want to emphasize the danger or difficulty of a step, as in the explanation of the second step of the hippopotamus example: "Although the hippopotamus is recumbent, its head remains active, and the animal can bite."

**Illustrations.** Instructions typically have more illustrations per page than other kinds of scientific documents [5]. The reason for the increased number of illustrations is that people often learn a process by seeing the process. Developing illustrations for instructions calls on your imaginative skills. The goal is to find perspectives, such as cutaway or blowup, that allow your audience to understand the process. For instance, shown in Figure 9-2 is a photograph of a setting in which you should not use a drugged capture of a hippopotamus. The surrounding water would provide an unsafe retreat for the drugged hippopotamus, leading to its drowning when the drug took effect.

**Figure 9-2.** Area in which the drugged capture of a hippopotamus should *not* be used. When drugged, hippos will try to submerge and, once drugged, will drown in depths as shallow as 15 centimeters.

## A proposal is an argument for how to solve a problem

Proposals move the money in science and engineering. From securing thousands of dollars to install photovoltaic cells on a building to raising millions of dollars to construct a wind power plant for a city, proposals stand as the documents upon which managers and government officials make important decisions. From a personal perspective, you can make a name for yourself in a company or laboratory if you can write a successful proposal to address a pressing problem.

From a format perspective, proposals range from single-sheet forms to bound documents containing hundreds of pages. In addition, different strategies exist for putting together proposals. Many proposals are individually written, while others are collaborative efforts involving large teams of engineers, scientists, managers, artists, and accountants.

Despite the wide spectrum of situations that you might face in writing a proposal, the perspectives of audience and purpose serve to classify proposals into three distinct categories. One category, which is common in industry, is a solicited proposal in which an agency or company asks someone to perform specific work. For example, a decade ago, the Norwegian oil and gas company Statoil put out a proposal call for computer simulations of the geology beneath the North Sea. Responding to this request, Simula Research Laboratory, which was a rising computational laboratory in Norway, submitted a proposal that Statoil selected from a competitive pool. Because Simula did excellent work that year, Statoil funded Simula's work in computational geology the next year and has funded Simula every year since [6].

A second proposal category, which is common in research, occurs when an institution such as the National Institutes of Health requests research about a problem such as Alzheimer's disease. In this situation, a government agency has a certain amount of funding to dedicate to a problem. In effect, the agency seeks proposals from researchers across the country so that the agency can select a suite of ideas to fund. In the case of Alzheimer's, some ideas in the suite might involve incremental improvements to the drugs that treat Alzheimer's, while other ideas might test bold strategies for preventing Alzheimer's from occurring. The first group of ideas would have a higher chance of success, but would produce only modest gains in the fight against Alzheimer's, while the second group would have a much lower chance of success, but offer the potential for large gains.

Yet a third type of proposals is one in which engineers or scientists approach a manager, company, or agency and request support for specific work. Through this type of proposal, many innovations arise. For instance, more than a decade ago, a small group of engineers at Pratt & Whitney came up with a strategy for adding gears to the compressor portion of a jet engine. The rationale for doing so was that the engine would use less fuel and run more quietly during initial and later stages of the flight. First, the engineers wrote and presented internal proposals to obtain resources to develop the idea. When the design showed promise, the group wrote and presented proposals to construct and test the design. When tests showed that this design worked, Pratt & Whitney rethought their business model to make the geared turbofan a feature on their jet engines. Because of the advantages of this design, within 5 years, Pratt & Whitney's market share for new orders of engines for regional jets rose from less than 10 percent to more than 90 percent [7].

When this idea for a geared turbofan was first proposed, many in the industry were skeptical. In fact, a CEO of another jet engine company proclaimed at an international conference that such a design was impossible. This skepticism points to the challenge for this type of proposal. In comparison with proposals in the other two categories, unsolicited proposals often face audiences who are skeptical about changes to the status quo. On the positive side, unlike the first two categories, this third type of proposal does not directly compete with other proposals. Still, such proposals request resources such as money, time, and equipment that could be used in other ways.

Proposals are challenging to write. One reason is the competition. In many research proposals, the odds of having your idea funded are low. For instance, in proposal competitions at the National Science Foundation, the percentages of proposals funded are typically one in ten. Put another way, for every research group that receives funding, nine research groups walk away empty handed. Granted, those losing groups can use the writing from their proposals in other documents, including other proposals. Still, losing a proposal on which you worked many long nights is deflating.

Another reason that proposals are difficult to write has to do with the content. In scientific papers, you write about events that have already occurred. In effect, you have results from an experiment or a computational analysis, and those results guide your writing. In a proposal, however, you write a plan for solving a problem. In other words, you write about what you will do, as opposed to what you have done. Describing imagined details is more difficult than describing actual details.

Despite the challenges, the writing of a proposal is a way for you as an engineer or scientist to change the world. In short, proposals garner support for ideas, and some ideas are game changers: drones, the iPhone, the Mosaic web browser, and the human genome project. To help you write effective proposals are the following three subsections. The first analyzes the thinking that goes into the decision whether to invest the time and energy into writing a proposal. Presented next is a subsection on a common organization for proposals. Finally, a third subsection presents winning strategies to incorporate into proposals.

**Deciding Whether to Go.** Preparing a proposal requires time and energy. Unfortunately, if your proposal does not win the contract, you receive no compensation. For that reason, you should carefully consider the constraints of proposals before committing your time and energy to the writing. The three most important constraints in proposal writing are the format, politics, and audience.

Although the formats of most unsolicited proposals are left to your discretion, the formats of most solicited proposals are explained in detail, usually in a document called the request for proposal (abbreviated as RFP). Details in the request for proposal include not only the layout and typography but also the length, the order of information, and often the names of the headings and subheadings.

Why are the formats of solicited proposals so specifically defined? One reason is that the client wants an efficient way to evaluate the incoming proposals. Often the client has an evaluation form for assessing the proposals, and the order of items on this form corresponds to the order of information specified in the request for proposal. A second reason is that the client wants a fair way to evaluate the proposal. You and other competitors would cry foul if all your proposals met the 15-page limit, while one competitor was allowed to submit a 25-page proposal, because the longer proposal would be able to include more supporting evidence.

A subtle reason that proposals are so specifically defined is that the client wants to see whether the submitters can follow directions. If the submitters cannot follow specific directions on the proposal's typography and layout, then how can the client expect the submitters to solve the complex problem that generated the proposal request? Similarly, if the submitters cannot hold the line on page-length restrictions, then how can the client expect the submitters to hold the line on budget restrictions? Failure to comply with the format usually results in the proposal being excluded from consideration.

When studying the format guidelines for solicited proposals, you should pay particular attention to unusual requests. For instance, early in my wife's career, she responded to a proposal request from a gas turbine company. In the request, the company listed a number of different measurement techniques and asked which ones the proposing laboratory could do *today*. At the time, my wife's laboratory could perform a variety of measurements for gas turbine research—from using thermocouples to measure temperature to using particle velocimetry to measure velocity. However, for each of those measurements, she would need several weeks for set-up and calibration. After going back and forth on this answer, she decided to write no experiments today, but did list the range of experiments that she could do with several weeks of preparation. Of the 27 researchers who responded to this pre-proposal request, only four (including my wife's) moved to the second round. Those four were the only four who wrote "no experiments today." The reason for that question was that this company had been burned by researchers promising to deliver results much earlier than the results actually came. As a result, the company wanted to start only with researchers who were honest about their schedules.

In determining whether a proposal is accepted, variables exist outside the quality of the proposed ideas and the quality with which those ideas are presented. These variables constitute the political constraints on the proposal. What types of projects is Washington funding this year? Is collaboration among companies, laboratories, and universities an advantage? How important are issues such as experience or geographical region? Although the amount of politics varies greatly across proposals, you should realize that in certain situations, no matter how strong your idea is and no matter how well you write the proposal, you will *not* win the contract. In some solicited proposals, for example, the funding institution or agency has someone in mind for the contract from the outset and has issued the proposal request only to fulfill a regulation. Likewise, for an unsolicited proposal within a company, a policy change in the works might preclude your proposed idea.

Given that some proposals will fail because of politics, you should find out as much as you can about a proposal situation before you commit your time and energy to the task. You should carefully read the request for proposal, call the contact person if you have questions, and honestly evaluate you and your ideas against the likely competition. These steps should not inhibit you from writing proposals; rather, they should guide you in deciding which proposals to write.

Although the politics suggests that your chances in a competition might be slim, you still might submit if your idea is innovative. In an NSF proposal competition for increasing the participation of women in science and engineering, my wife believed that she and her team at Virginia Tech had a good idea. However, a number of team members were discouraged because the number of competitors was high, the number of awards was few, and several competitors had already received feedback from the previous year's competition. As the proposal submission date drew near and the editing load became heavy, several team members announced that they wanted to pull out. In a matter-of-fact manner, my wife told the team members that they could quit, but that she and those remaining were submitting the proposal. From my wife's perspective, the team had invested too much time and energy into the proposal to stop now. Reluctantly, the vacillating team members stayed on. As discussed later in this section, the team's efforts paid off because despite the political odds, their proposal won.

Given that many proposals will fail because of politics or strong competition, you should look at the success of your proposals not in terms of the proposals that you write in a single year, but in terms of the proposals that you write over several years. In a pool of proposals that you have written over that time, while many of your proposals will be decided on politics, many others will be decided both on the merit of your ideas and the quality with which you communicate those ideas.

Fortunately, the effort spent on writing one proposal often carries over to the writing of other proposals. For instance, a "Statement of Problem" or "Facility Resources" section that you write for one proposal can often be adapted for other proposals. This adaptation does not mean that you simply cut and paste the old text into the new proposal; instead, such an adaptation means that you use the old text to help draft the new proposal. You still have to rethink, revise, and polish that old text so that it fulfills the constraints of the new proposal request.

Unlike the typical audience for emails, which consists of one type of reader, the typical audience for proposals contains at least two types of readers: a technical audience and a management audience. The technical audience reviews proposals to see whether the science and engineering in the plan are sound. In contrast, the management audience reviews proposals to see whether the proposed plan is feasible from the perspectives of time and money. Even in a proposal written to only one reader, say a manager within a company, that reader will look at the proposal from both a technical perspective and a management perspective.

In writing a proposal, you have to address both audiences. Perhaps the best way to envision your readers is to put yourself in their positions. For solicited proposals, the request for proposal allows you to do just that. From reading a well-written request for proposal, you know who the readers are, why the readers have requested the proposal, the level of detail that you should present in your proposal, and how the audience will evaluate the proposal. In other words, you know the answers to the same questions about audience that you should ask yourself before writing a report or journal paper.

Assume for the moment that you are on the other side of the table in the proposal process. In other words, assume that you are the audience, rather than the writer, for a proposal. As an example, imagine that you are a fish-and-wildlife commissioner who oversees a park called Fire Lake [8]. Fire Lake is a fisherman's haven with bass, bream, and trout. Over the past few years, though, your commission has received numerous complaints from fishermen stating that the number of fish in Fire Lake has declined. To determine whether these complaints have a basis, your commission has decided to hire someone to count the fish in Fire Lake. Because you do not have a "fish-counter" on contract, you are obligated by state law to accept proposed bids from "fish-counters" across the state. What kind of information do you put in the request for proposal?

Well, one thing that you would want to know is the cost. You would not want to award the contract to someone who has a blank check with your signature on the bottom. If you did and if you hired someone who was unscrupulous, you might receive a bill that severely dents your budget. Besides cost, you would want to know the schedule for the work to verify that the work will be done in a timely manner. Otherwise, you might end up with a "hippie" fish-counter who comes in with a "low-ball" bid of only 60 dollars per week until the job is completed. The problem with the hippie fish-counter is that the job never gets completed. The hippie fish-counter is content to live on 60 dollars a week. In fact, the hippie fish-counter plans to pitch a tent on the banks of Fire Lake, listen to the Grateful Dead, and count fish indefinitely.

A third aspect of the proposal request would be the type of information that the fish-counter actually presents. Will the fish-counter present just the total number of fish in the lake, or the number of fish within each species? The number of fish in each species is much more useful. For one thing, you could have about the same number of fish as you did 20 years ago, but if all those fish are carp rather than an assortment of bass, bream, and trout, then you have a problem. Besides knowing the number of fish within each species, you would want to know how accurate the numbers are. Within 10 percent? Within 20 percent? Along these same lines, you would want to establish guidelines for an acceptable accuracy.

A case occurred in San Francisco in which the city hired a consultant to estimate how many people would show up for the 50th anniversary of the Golden Gate Bridge. For the celebration, the city had decided to close the bridge to automobile traffic and allow people to walk across, just as they had done during the grand opening 50 years before. The consultant who won the contract performed surveys and announced a few weeks before the celebration that about 50,000 people would show up to walk across the bridge [9]. On the basis of that number, the city ordered an appropriate number of buses and policemen. In addition, the city allotted four hours for the bridge to be closed to automobile traffic and had orange cones placed in the center of the bridge, so that pedestrians from the San Francisco side of the bridge could walk on one side of the cones and pedestrians from the Marin side could walk on the other.

The morning of the celebration came, and instead of 50,000 people arriving, more than 800,000 people arrived. Because not enough buses were on hand for all the people wanting to get to the bridge, the streets near the bridge became jammed with double and triple parking. Worse yet, the bridge became gridlocked with people and could not be cleared. In fact, the bridge became so crowded that people started climbing onto the scaffolding of the bridge because their claustrophobia overcame their acrophobia. Afterward, the city petitioned to get back the money from the consultant who had given the inaccurate crowd estimate, but because the proposal request had no specifics about accuracy, the courts ruled that the consultant could keep the money.

A fourth consideration for your proposal request would be finding out the methods that the fish-counter will use. Otherwise, you might hire a psychopathic fish-counter who presents you with a low bid ($200), a reasonable schedule (2 days), and an incredible accuracy (within one fish). What you would not realize without knowing the methods is that this psychopathic fish-counter plans to purchase $100 worth of poison, dump it in Fire Lake, wait a couple of days, and then announce that you have exactly zero fish.

**Organization.** An unusual stylistic aspect of proposals is their overall organization. Unlike other documents that follow an introduction-middle-conclusion organization, the organization for proposals essentially consists of two parts. The first part presents a problem or opportunity that needs to be addressed. This problem or opportunity can be thought of as a void in a puzzle. The second part of the organization, which is the proposed plan, is the solution piece that fits into the void.

Most proposals will also include at the beginning a summary, but this summary maintains the overall organization by distilling the problem and proposed solution into a single section. In proposals that are reviewed by a committee, the summary is especially important because while only one or two people around the table might read the entire proposal, everyone will read the summary.

The first part of the proposal's organization, often titled the "Statement of Problem," shows that the writer understands the problem that has generated the proposal request. Although taken for granted by many scientists and engineers, this section is highly valued in the scoring of proposals, especially unsolicited proposals and research proposals to funding agencies such as the National Science Foundation. In both of these types of proposals, this section also makes the audience aware of how important the problem is.

In stating the problem, you should show, not just tell, the audience that a problem or opportunity exists. For example, if you desire funding to study ways to reduce the space debris that is orbiting the earth, you would have to show that a substantial amount of debris exists in orbit and that this debris poses a problem. In the following excerpt from such a proposal [10], notice how the author uses example after example to back up his points.

> Currently, NASA is tracking more than 7000 artificial satellites in orbit about the earth [11]. Of these satellites, shown in Figure 9-3, only 6 percent represent functioning satellites. The other objects orbiting the earth are considered space debris. The smallest size being tracked is 10 centimeters in diameter, or about the size of a baseball [12]. In addition to the debris being tracked, an additional 30,000 to 70,000 objects between 1 to 10 centimeters are too small for tracking [11].
>
> The debris includes operational debris, which is produced during normal space activity. Sources of operational debris include experimental equipment, astronaut possessions, and human refuse [13]. For example, in the early 1960s, an experiment called the "Westford needles experiment" released numerous copper needles in orbit about the Earth. The experiment's goal was to release large quantities of small copper dipoles resonant at x-band and radio

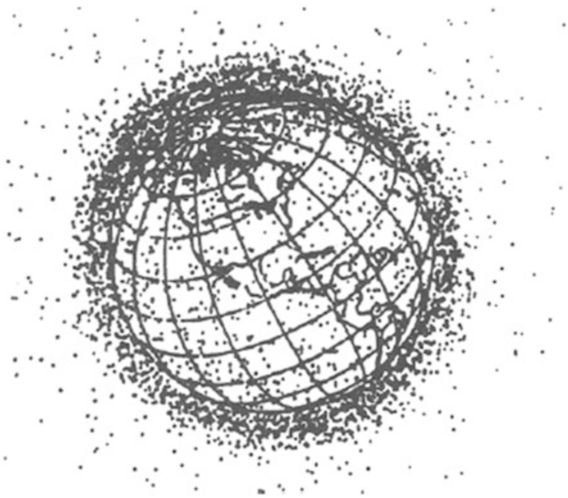

**Figure 9-3.** Computer representation of the more than 7000 artificial satellites that are being tracked in their orbits about the earth (representation courtesy of Teledyne Brown Engineering). Less than 6 percent of these satellites represent functioning satellites; the rest are space debris.

frequencies at a moderate altitude of 3,900 kilometers. Not only did the experiment not work, but many of those needles are still in orbit today. Operational space debris has also been created by astronauts. For instance, during the first American space walk in June 1965, one of Ed White's gloves drifted out of the Gemini spacecraft. In another mission, a Challenger astronaut lost a powered screwdriver and several screws while repairing the Solar Maximum satellite [14]. In still other situations, Gemini and Soviet astronauts threw bags of garbage overboard [11].

Besides operational debris, the orbital space debris also includes micro-particulate matter, such as solid-propellant fuel particles, paint flakes, and thermal coating particles. Compared with the large objects of operational debris, the micro-particulate matter might appear to be a negligible threat. However, these particles can obtain high orbital speeds in space that increase their threat to space activity. For instance, a paint chip caused a 4 millimeter crater in a window during a 1983 mission of the Space Shuttle Challenger [14]. This particle was travelling at 3 to 6 kilometers per second and because of the severity of the impact, the window could not be reused [11]. In another example, one impact from a particle penetrated three layers of a seventeen-layer blanket retrieved from the Solar Maximum satellite. Analysis of the impact crater showed that the particle was probably an ice crystal from the Shuttle waste management system. Scientists fear that these particles could cause much greater damage. For example, a paint chip travelling at 10 kilometers per second could puncture an extravehicular space suit [14].

This problem statement was straightforward to develop because the writer required only two steps to make a case for removing orbital debris: (1) showing that much orbital debris exists, and (2) showing that this orbital debris was dangerous to future space missions. Consider another example in which the proposed work is not quite so easy to justify. In this example, notice how the authors methodically move from one point to another until a bridge is formed between a widely recognized problem (increasing the efficiency of airplane engines) to one not nearly so recognized (finding a way to produce high turbulence) [15].

> In gas turbine engines, such as jet airplane engines, the higher the combustion temperature, the higher the engine efficiency. At present, the combustion temperatures desired for these engines are much higher than the melting temperatures of the blades in the engines. For example, a common situation is a turbine blade with a melting temperature of 1000 K operating in conditions in which the turbine inlet temperatures are 1700 K [16]. To achieve these higher combustion temperatures, the turbine blades are cooled.

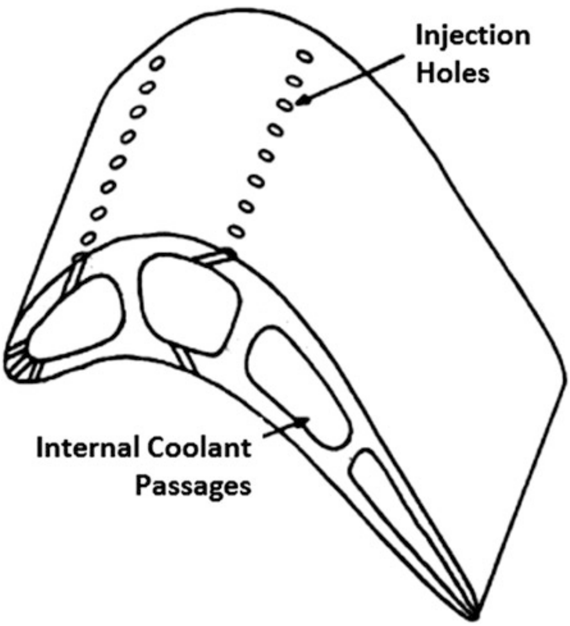


**Figure 9-4.** Gas turbine blade with film cooling. A coolant such as air travels through the internal coolant passages and comes out through the injection holes to cool the metal blade.

> A common method for cooling the turbine blades is film cooling. In film cooling, a cold fluid is injected through the blade surface. This injection results in a cooling film between the hot combustion gases and the metal surface of the blade. The typical geometry of a film-cooled turbine blade is shown in Figure 9-4.
>
> The effectiveness of film cooling depends on a large number of variables including the hole geometry, pressure gradient, blade curvature, and freestream turbulence level. To design turbine blades that use film cooling, manufacturers have to predict the convective heat transfer in the turbulent boundary layers on these blades.
>
> Typical freestream turbulence levels that occur over turbine blades have been measured by Koutmos and McGuirk to be greater than 20 percent [17]. All of the literature studies, however, on the effects of freestream turbulence on heat transfer have been done with turbulence levels less than 7 percent. Why? The high freestream turbulence levels of interest (20 percent) cannot be generated and sustained by standard techniques for generating turbulence. The only study that has achieved turbulence levels greater than 20 percent was done by Maciejewski and Moffat [18]. Recognizing the need for any data that would indicate the effects of high freestream turbulence on heat transfer, Maciejewski and Moffat placed a test plate along the edge of a turbulent free jet. While this experimental condition had the advantage of producing high freestream turbulence, it had definite drawbacks in that the mean velocity field was nonuniform and decayed rapidly along the test plate. Ideally, what is needed is a device for producing high freestream turbulence that has a uniform mean velocity field and that does not decay rapidly downstream.

After presenting this problem, the authors were in an excellent position to propose their work: a new design for a turbulence generator that achieved high turbulence (above 20 percent), but maintained a uniform velocity field.

While the problem statement shows the audience that a problem exists and that the author understands that problem, the second part of a proposal (the proposed solution) presents the audience with a plan for addressing the problem. When well written, this section answers the questions that the audience has after reading the statement of the problem. These questions depend on the type of proposal. For instance, in a research proposal to a funding agency such as the National

Science Foundation, typical questions after the problem statement would be as follows:

1) What is the proposed solution?
2) Does the solution make sense from a technical perspective?
3) Does the solution make sense from a management perspective?
4) Can the people making the proposal carry out the solution?

In answering the first question, you present the scope and limitations of your solution. In this part of the proposal, you show how your solution addresses the problem raised in the first part of the proposal. For instance, if your solution to remove space debris is a huge foam balloon that acts like a collector satellite [19], then you should explain the type and amount of debris that this satellite could remove. While the problem statement has created a hole in science that needs addressing, the proposed solution presents a plan that fills that void, much in the same way that a puzzle piece fills a void in a jigsaw puzzle.

In answering the second question, of whether the solution makes sense from a technical perspective, you target the technical audience for the proposal and discuss how you will solve the problem. In the example of the satellite for collecting orbital debris, you would explain the different stages of the proposed work: design of the collector, testing of the collector, placement of the collector into orbit, and collection and disposal of the debris. In answering this second question, you not only present the methods that you will use to solve the problem but also justify why you chose those methods.

In answering the third question, of whether the solution makes sense from a management perspective, you discuss again how you will solve the problem, but you target the management audience in this discussion. For that reason, you discuss issues that concern your management audience: the cost of the solution, the schedule for the solution, the effect of the solution on the environment, and the effect of the solution on the safety and health of those people involved. In presenting this information, you respond to the specific questions that your management audience has: Is the solution worth carrying out? Will the solution be carried out in a timely manner? Will the solution have negative effects?

Another aspect of this question is to discuss the effect that the solution will have on the stated problem. In the example on creating a high turbulence generator [17], notice how the author shows this effect:

> The proposed experiments will help us to predict the heat transfer coefficients for the external surfaces of gas turbine blades. By predicting the heat transfer coefficients, and ultimately the blade temperatures, we can use computer modelling and experimental testing to improve the design of blade cooling. This improvement can have a dramatic effect on blade life. For instance, reducing the blade temperature from 1140 K to 1090 K increases the blade life from 560 hours to 3900 hours [20].

Depending on the situation, the effect on the stated problem can have multiple levels of depth. For instance, in the proposal for a satellite collector of orbital space debris, the effect would certainly include how much orbital debris the collector will remove. A deeper discussion, though, would show how this collection will affect the space program. For instance, how much safer will future space missions be because of the orbital debris removed by the collector?

Finally, in answering the fourth question, of whether the person(s) making the proposal can carry out the solution, you show your readers that you are qualified for the task. Here, you present evidence for your qualifications, your experience, and your resources. Ideally, you should interweave this information in natural ways through the proposal. Both the management and technical audiences review this information to determine whether you can, in fact, be trusted to carry out the work. Often supporting this argument in a proposal is a résumé in which you summarize your education, experience, abilities, and accomplishments. How you order the categories of a résumé and how much space you devote to each category depend on your background and the expectations of the audience. For instance, if the proposed solution includes experimental tests, presenting your experience on relevant experimental techniques becomes important.

Given how quickly that résumés are read, you should format your résumé so that your outstanding characteristics are easy to locate. In this type of document, vertical lists serve because the items can be located quickly. In such lists, though, you should make sure that the items are parallel—for instance, all noun phrases or all participial phrases.

Although most proposals do not require a conclusion, some would benefit from having one. For instance, in the NSF proposal competition mentioned earlier to increase the standing of women faculty in science and engineering at universities, my wife's team included a conclusion that discussed how the situation on campuses would change if the proposed idea were enacted. Such a conclusion provides closure for proposed ideas, especially those that could significantly improve people's lives.

**Winning Strategies.** Over the years, I have had the fortune of working with a number of talented teams that have won large proposals—both in the United States and in Europe. All those teams had one common characteristic: a good idea worthy of funding. In addition, on the proposals in which the competition was stiff, all the proposals had another common characteristic: a writing strategy that made the proposal stand out. This subsection discusses three such winning strategies: (1) sticking the beginning of the proposal, (2) emphasizing the assertions of the proposal's main argument, and (3) showing the proposal's idea in a graphic.

***Stick the beginning***. For an author attempting to sell her or his first novel, the first few sentences are critical. Because so much competition exists in the publication of first novels, most editors begin reading such novels with the mindset of finding a reason to turn down the submission. Given how many hundreds of novel manuscripts are submitted each year to a publishing house, such a mindset is natural. As a result, fiction writers work especially hard on the novel's beginning.

Given the relatively low odds that exist in many proposal competitions, engineers and scientists should do the same. In essence, proposal writers should try to change the reviewer's mindset from why should they turn down this proposal to how to persuade the committee to accept this proposal. Such a change requires cogent arguments and memorable details. Consider the first paragraph from the summary of a successful research proposal to the Norwegian Research Council:

> Every 45 seconds, a person in the Western world suffers sudden cardiac death. In addition, every 45 seconds, a person dies from a different condition: heart failure. These two conditions are the major challenges in modern cardiology. Although advanced treatments exist for patients when drugs have no more to offer, the problem is to know when and how to apply these treatments. The goal of our proposed Center for Cardiology Innovation is to produce technological innovation in cardiology diagnostics and applications that can solve this problem [21].

This opening provides two powerful statistics that begin to define the problem. The two statistics are powerful because 45 seconds is a time interval that the audience can easily grasp. In addition to providing the statistics, the third sentence of the paragraph provides an authoritative insight about the problem. The effect of such an insight is that the authors begin establishing credibility with the audience.

Not all research areas have such succinct statistics with which the authors can establish a problem. Consider a different type of opening for another successful research proposal to the Norwegian Research Council, but in a much different area of science: verification and validation of software.

> Ariane 5's maiden flight on 4 June 1996 failed, with the rocket self-destructing after 37 seconds, because of a malfunction in the control software. History is full of examples of software bugs that have caused severe damages: planes have crashed, patients have died from incorrect medication, missiles have missed their targets in war, and key financial systems have broken down. In spite of the large investments in verification and validation activities, we frequently read about serious software failures in the press [22].

In this example, the author began with a specific example, but then provided the authoritative insight that such examples are common. As in the first example, showing such an insight built credibility for the authors. Note that the last sentence of this opening paragraph anticipated a counterargument. From a proposal that the Norwegian Research Council turned down in a previous year, the authors knew that reviewers were frustrated about funding this area of research. The reason was that despite large investments in this type of research, many software failures still occurred. Given that, the authors wanted to show that they recognized this frustration. Later in the proposal, the authors discussed in much more detail the reasons for these continuing failures. Likewise, the authors also discussed how their proposal would address those reasons. In essence, the first paragraph previewed a counterargument that the authors would address.

In both of these two examples, the authors began in a memorable way. Finding an opening that is memorable requires much thought. No single strategy works for every proposal. An excellent resource, though, on how to make an opening memorable is the book *Made to Stick* [23]. In addition to having a memorable beginning, each of the two example openings planted seeds for other arguments. The first example planted a seed for the credibility of the authors, and the second example planted a seed for a counterargument to address a concern of previous reviewers.

When the stakes are high or the competition is steep, authors have to balance the value of an argument against the space in proposal that the argument consumes. That balance is particularly important for the proposal's opening, where the page space receives so much attention. For instance, if you were to propose a new generation of supercomputers for the U.S. national laboratories, you might just state the amount of storage in the next generation of supercomputers or the number of arithmetic operations per second. However, William Wilson from Sandia National Laboratories went beyond that and presented the dramatic example discussed in Lesson 6:

> By the late Middle Ages, cities throughout Europe were building Gothic cathedrals. In this effort, citizens dedicated their entire lives to the construction of a single cathedral, often in competition with other cities for the highest or widest building. The only way,

> however, that architects could test a new design was to build a cathedral, a process that took over forty years. Unfortunately, many cathedrals caved in during or after construction because the designers had no way other than trial and error to test their designs. What took forty years to test in the Middle Ages could have been done in minutes on a supercomputer [24].

Following this paragraph, Wilson backed up his example with an illustration (Figure 9-5) showing a supercomputer design of a cathedral that proved successful (left image). Next to this design was a supercomputer design of a cathedral that failed (right image). After the proposal was published and distributed, Wilson flew to Washington to give a follow-up proposal presentation. Every proposal reviewer whom Wilson met remarked about the cathedral example. In Wilson's case, the example was well worth the space spent.

In some proposals, you should take risks at the beginning, particularly if you think the reviewers might have a bias toward your competition. For instance, in the NSF proposal competition mentioned earlier to increase the standing of women faculty in science and engineering at universities [25], my wife's team at Virginia Tech decided to begin with a story. Given that the story would use one entire page of the allowed

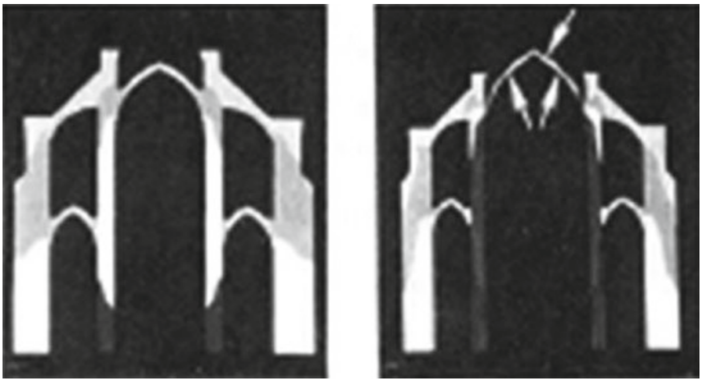


**Figure 9-5.** Two supercomputer designs for a Gothic cathedral, with the cathedral height underneath [24]. The supercomputer found that the cathedral design on the left worked, but the design on the right failed.

15 pages in the proposal, the story was a risk, but my wife's team decided that they needed something different to stand out. After interviewing several women faculty in these fields, I created a composite story to capture the problems that the women faculty faced. As it turned out, the story was a difference maker. The reviews of the winning proposal revealed that the story's fictional woman, whom I named Gail, impressed the reviewers—each one commented on her by name. In another large proposal that called for creating a national outreach program (the Engineering Ambassadors Network) to recruit talented and diverse students into engineering [26], I began with another story. Although this one told the events of an actual outreach visit by six female engineering undergraduates to a high school in Pittsburgh, the story had a similar effect. While a story would not be appropriate for most proposals, these two examples point to the importance taking stylistic chances with the beginning of a proposal when you want to stand apart from the competition.

***Emphasize your assertions***. Arguments are built on assertions, which are supported with evidence. For instance, in the proposal in the 1980s that designated Texas as the site for the superconducting supercollider project [27], the authors had three main assertions:

1. A site for the supercollider had to meet 13 criteria.
2. The Texas site was the only site that met those criteria.
3. Therefore, the Texas site should be chosen.

To establish the 13 criteria of the first assertion, the authors relied on referenced measurements and statistics. To support the second assertion, the authors applied those 13 criteria to a map of the United States to show which areas met the criteria. In the end, only one small portion of the country (near Waxahachie, Texas) met all 13 criteria. The third assertion then was a logical deduction of the first two claims.

In their proposal, the authors of the Texas proposal did an excellent job of emphasizing their assertions. However, many proposal authors bury the assertions of their main argument in the middle sentences of paragraphs. Such a strategy undermines the argument, because as Stephen Toulmin asserts: Audiences are more likely to believe an argument if they know and appreciate the assertions [28]. So how can you make your assertions stand out in a proposal?

Certainly, you can use the advice of Lesson 8 and place your assertions in high profile positions: the beginnings of sections, the ends of sections, the beginnings of paragraphs, or the ends of paragraphs. However, that placement might not be effective enough in competitions in which only one or two reviewers read the proposal all the way through, while the other reviewers read only the summary and skim the rest of the proposal.

One of my recommendations is to place the main assertions of the proposal as the headings of sections. That way, the assertion appears in a boldface font that is both larger than the rest of the text and separated with white space. For all proposals in which the headings are not prescribed, I rely on this strategy. For instance, I used this strategy on the proposal for creating the Engineering Ambassadors Network [26]. Not only did the argument's assertions stand out, but the exercise of stating the most important takeaway of each section made our proposal more focused. These same advantages occur in the creating sentence headlines for ***assertion-evidence*** slides [29]. Likewise, these same advantages occur in writing sentence headings for a report or book. As you might have noticed, the major headings in this book are sentences. As with the sentence headlines of assertion-evidence slides, each sentence heading should be no more than two lines long, should be justified on the left margin, and should be capitalized as a sentence would be.

Although effective, this assertion-heading strategy will not work for those proposals in which the headings are specified by the requesting institution. In such situations, you could still make the assertions stand out by placing each one in a pull-quote. Regularly used by news magazines, pull quotes draw the reader's eyes to a short sentence on the page. For an example, see Figure 9-6. Although proposal guidelines specify the minimum size of text, they do not limit the maximum size of text. By placing your key assertion in pull quotes, you ensure that even audiences who are only skimming the proposal will read your main assertions.

Finally, as Toulmin discusses, you want to make sure that the audience appreciates each assertion. In other words, an audience might understand that your research question is to determine whether the dunlins of Iceland are a different subspecies from the dunlins of the Baltic [30]. However, the audience might not appreciate this assertion unless they know that because the dunlins of the Baltic are declining, a risk exists that a subspecies is threatened with extinction. Toulmin uses the word ***warrant*** to label such background information. In an argument, a warrant can be as important to provide for an assertion as the supporting evidence is.

***Show your idea visually***. In November 2009, Simula Research Laboratory began writing a research proposal on a strategy to

**Motivation**

In 1987, Oslo initiated a project to develop an electronic ticket system for buses, trams, and trains in Oslo. In the late 1990s, after spending 318 million NOK, the project was canceled. In 2002, the decision to develop the electronic ticket system was made again, and the estimated launch was to be at the beginning of 2006. The amount was initially 200 million NOK.

During 2005, 180 ticket machines were placed at different train stations ready to be tested. However, the target date of starting up the system at the beginning of 2006 was not met because Oslo Sporveier discovered several problems during the system testing. Today, in 2008, the system is still not up and running. The delay is now more than two years, and the amount invested since 2002 is 235 million NOK [1]. Still, there are problems with functionality and system development that need to be solved. For example,

*The debacle of Oslo Sporveier reveals how important it is to estimate the effort needed for developing software.*

**Figure 9-6.** Example of a pull-quote from a proposal on validation and verification of software [22].

reduce deaths from heart disease [21]. The proposed idea was to incorporate a patient's ultrasound and electrocardiogram measurements into a computer simulation tailored for each patient. Not only would the simulation produce an individual treatment plan, but the simulation would be able to predict the next set of ultrasound and electrocardiogram readings for the patient. If the next measured readings were not as strong as predicted, the simulation would then prescribe changes in the patient's treatment.

With less than a few weeks before the April deadline, some team members wanted to pull out of the competition. These members felt that the proposal, still in the draft stage, would not win. Molly Maleckar and Sam Wall, who were Simula computational scientists leading the proposal team, disagreed. Although the team still had much writing to do and the competition for this proposal would be stiff, the idea of the proposal was novel. In addition, the proposal partners were strong. Simula was a respected computational simulation group in Europe, and Oslo University Hospital was the best Norwegian hospital for cardiac research. What the team needed to do was to craft a proposal that conveyed the content. In the next few weeks, Maleckar and Wall did just that, garnering 10 million dollars for the research.

In addition to the strong opening that was shown earlier in this section, Maleckar and Wall followed my suggestion of showing the proposal's novel idea in a graphic. Shown in Figure 9-7, this graphic was particularly valuable for the reviewers who did not read the proposal all the way through. Although reviewers will not read every paragraph in a proposal, they generally will examine every illustration. In effect, the illustration provided emphasis to the proposal's idea, which in this case was a strong one. No doubt, such an illustration occupies valuable space, but given the emphasis that such an illustration receives and how effectively an illustration can convey certain ideas, the trade-off is usually worthwhile.

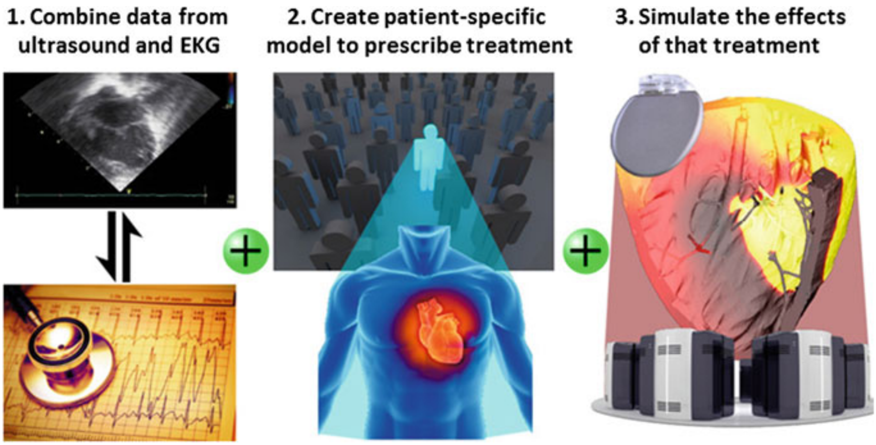


**Figure 9-7.** Proposal illustration that showed the document's main idea: a three-stage strategy for treating patients with heart disease [21].

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# Using Your Writing Time Efficiently

*Plan your work for today and every day, then work your plan* [1].

—Margaret Thatcher

Scientific writing is hard work. Granted, it is not as physically exhausting as swinging a pick or as mentally demanding as solving a nonlinear differential equation but it requires focus and patience. Moreover, the solutions are not exact. You do not draft a document and sit back and say, "Perfect." No matter how many times you revise a document, you will find phrases that will not sound quite right and the beginnings of sentences in which you feel compelled to state five details at once.

Scientific writing is often lonely work. Although you might brainstorm ideas in a group or solicit sections of a document from other people, the process of sitting down to write calls for periods of solitary confinement. Just because scientific writing is difficult does not mean it is drudgery—far from it. Writing a scientific document demands energy. You have to convey complex ideas and images. Strong scientific writing also demands imagination. You have to detach yourself from your work and place yourself in the position of your audience. Moreover, you will find that writing a strong document challenges not only your writing skills but also your scientific skills. When you write to inform and to persuade, rather than to impress, you see your own theories and experiments as your audience does. Doing so makes you a critic of your own work. To paraphrase Francis


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9_10

Bacon, reading makes you knowledgeable, presentations make you ready, and writing makes you exact [2].

So where do you get started? Most professional writers, no matter whether their work is fiction, journalism, or scientific writing, follow the same general process of writing: preparing, drafting, revising, and finishing. In the preparing stage, the first hurdle is assembling content worthy of your audience's time. Although you should not wait to begin writing until every result has been recorded, mapped, and plotted, you should not invest time drafting a scientific document that has no destination.

A second hurdle of the preparing stage is an understanding of your audience, purpose, and occasion. Foremost here is the audience. Before writing, you should have an idea about who will read the document, what they know about the work, and why they will read the document. Without an audience, you will not know which parts of the work to emphasize, what background information to include, which words to define, or how detailed to make your illustrations. Also important will be the purpose. For example, are you having the audience simply understand your work or do you want them to fund your work? Finally, before placing words onto paper, you should know at least one aspect of the occasion: the length of the document. Will you be writing two, twenty, or two hundred pages? Length directly affects depth, which in turn affects other aspects of style.

Assume that you have valuable content to write about and that you have the immediate questions answered for audience, purpose, and occasion. Let us say that you have spent the past couple of years studying whether additive manufacturing, often referred to as three-dimensional printing, could create parts for the hot portion of jet engines. Although your work has found that highly stressed parts such as rotating turbine blades are not suitable to be additively manufactured, other parts such as cooling channels within stationary vanes are. Moreover, because these cooling channels have intricate designs, additive manufacturing offers many advantages. You envision wavy channel designs that current manufacturing techniques simply cannot produce.

You not only have visions; you have results. As shown in Figure 10-1, for a cylindrical channel, you examined the geometric shape and surface roughness from three different build orientations: horizontal, vertical, and at a 45-degree angle [3]. Your testing included computed tomography scans (CT scans), as shown in Figure 10-2, for the inside of each channel [4].

You also know the constraints of format and audience. The audience is challenging because it is so varied: engineers from gas turbine companies, engineers in additive manufacturing, and officials from the Department of Energy (DOE) and the Federal Aviation Administration (FAA). Within this mix of audience, political considerations arise for the document. Because of the extremely high temperatures in this portion of a gas turbine engine, many in the audience are skeptical about additively manufactured parts being able to survive. Nonetheless, you see additive manufacturing as a major advancement not only to bring down costs of gas turbine engines but also to make the engines more efficient and cleaner burning.

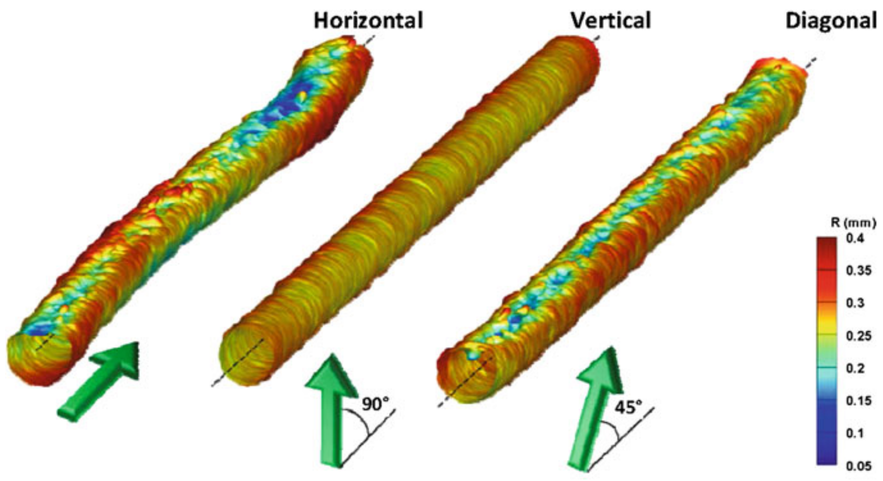


**Figure 10-1.** Image that shows how the build direction of an additively manufactured channel affects the quality of the channels. For instance, a vertical build direction leads to having the most cylindrical shape and the least amount of surface roughness. For the legend, *R* is the local radius of the cylinder.

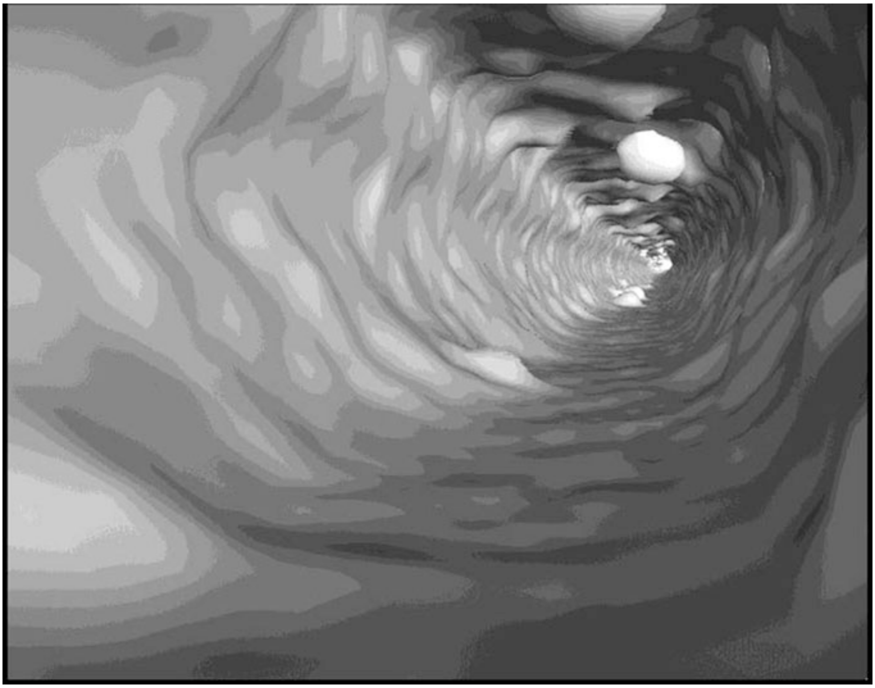

**Figure 10-2.** Computed tomography scan (CT scan) for the inside of a cooling channel created through additive manufacturing. Such an image aids in determining the geometric shape and surface roughness of the channel's inside surface.

Your supervisor sees something too because she is eager for you to publish your work. "Have you written your conference paper?" she asks you.

"No, not yet," you say.

Your supervisor stares at you for a moment. She has a casual look about her that is deceptive. Her office suddenly feels hot. "I'll be seeing something soon," she says.

"Soon," you say. "Soon."

You go back to your office where Hank Wilson is waiting. Hank Wilson wants to talk about the Pirates. You remind yourself that your father's heroes—Clemente, Stargell, and Alou—no longer play the game, and that many of the people who do play the game receive more money in a year than you will earn in your lifetime.

Hank starts in about last night's game where the Pirates came up with two runs in the bottom of the eighth to come back against the Reds. "It started with a couple of singles, both grounders with eyes, and then McCutchen ripped a double to the gap."

Hank's story reels you in for a moment but you remember your vows. The problem is that the Pirates are only two games back in their division, and as long as you can remember, you have been a diehard Pirates fan. As a kid, the reason was silly: You wanted them to win the series so that you could go to a ticker-tape parade. As you grew older, you wanted the Pirates to win a series for the simple reason that you had been waiting so long. Through the years of Bonds and Bonilla and van Slyke, you waited, reading box score after box score, staying up nights to catch radio broadcasts from the west coast, relishing each win, and suffering with each loss. You hesitate a moment, watch the light flicker in Hank's eyes, but do not give in.

Even if you wanted to talk about baseball, you cannot. You have a conference paper to write. What should you do? You cannot write here with Hank talking about baseball. The conference room, you think. "Catch me on it later, Hank," you say. "I've got to write my paper."

You are almost to the conference room when the project leader stops you. "I just sent you an email," he says.

"I'm working on my conference paper," you say.

"The email is just a reminder about the *Quarterly Report*," he says.

For one instant, you think about moving on but you are responsible for the additive manufacturing section of the *Quarterly Report.* The technical update you could whip out in an afternoon but what slows you down is the management items: milestone charts, procurement summaries, fiscal plots, and contract distributions.

"By Friday," he says.

"Friday?"

"Don't look at me. DOE pays the bills around here."

"But I've got to write my conference paper."

"That's fine," he says. "As long as your section is in by Friday."

You go back to your office. Hank Wilson stares bewildered as you walk by. You try to ignore him. At your desk, you begin reading. You are only halfway through summarizing what your team accomplished in the last quarter when a professor from Ohio State calls. His group is beginning to research additive manufacturing in gas turbine engines, and he wants to see your group's latest publications. Although his group would be a competitor with your group on research funds, you are not concerned. Your team has a significant head start, and the papers tell only part of the story. You promise to email him the papers.

At your desk, you push through the *Quarterly's* milestone charts and fiscal sheets and begin checking the procurement summaries when a computer scientist from analytical modeling stops by. Last week, she had made this appointment, which you had forgotten. Thank goodness, you were in the office. You force a smile and invite her in. She wants to adapt your three-dimensional printing methods to create implants for hip replacements. She has several questions about your code—questions you try to answer off the top of your head but cannot. So, you dig through your old notes and old files and notes on where to place the supports, how to set the printing parameters, and what the powder type is. By the time she leaves, it is well past five o'clock. You are tired and hungry. What now? You decide to go home and return here tonight, when no one is around and you can take the phone off the hook and write.

You arrive home and find in your mailbox a bill from the power company. In red letters across the top of the bill are the words "Second Notice." Because you are sure that you have already paid this bill, you throw it in the wastebasket. Then you pick it out. There is something frightening about throwing away an unpaid bill. You need a good meal, you think. After all, you have much writing in front of you. You go to Bangkok Garden for Phad Thai. While you eat, you grab today's newspaper from the counter and glance at the sports section. Glancing at the box scores is okay, you decide. Reading about baseball is not actually watching baseball, and that was your vow: not to watch another baseball game until you finish your report. The Pirates play in St. Louis this weekend. St. Louis has never been kind to the Pirates.

It is almost eight o'clock by the time you return home. You are tired and you decide to rest a bit—just lie down on the couch and think about what you are going to write

When you wake, it is quiet and dark outside. You look at the clock: 11:43. The day is lost.

## Preparation puts you into a position to succeed

Scientific writing is a craft that requires preparation. You will find it difficult to jump right into writing a document. Most professional writers have disciplined schedules. Although you as a scientist or engineer cannot alter your entire job description just to finish one document, you can make simple adjustments.

The first thing you should do before writing is to clear your mind. You have to put aside your personal problems and the bills you have due. You have to think about the work and the audience. One way to clear your mind is through sleep. Hemingway used this method. His writing day began each morning after eight hours of sleep. Another good way to clear your mind is through motion: walking, running, and mowing the lawn. Wright Morris walked twice a day, before and after writing. Shirley Jackson also was a walker—in fact, the idea for her famous story "The Lottery" arose while pushing her baby in a stroller through the neighborhood. Harper Lee played golf. Max Apple and John Irving are avid runners. Agatha Christy washed the dishes, even when they were not dirty. Mowing is okay but you have only so much lawn. Driving allows you to daydream but driving and daydreaming at the same time is dangerous. Running, walking, and cycling are the best. These activities give you the chance to think about the structure of the document, play a strategy through in your mind, and see whether it makes sense. I prefer an early morning walk with my dogs—about an hour, not so long that I am tired but long enough that I daydream. After taking the walk, I do not eat much more than a cup of cereal.

The second thing you need is a block of free time. For drafting a document, a good writing block is one to four hours. Even after sitting down at your desk, you usually need ten minutes or so just to get in the groove of writing sentences of value. Do not think, though, that you can continue writing for the whole day. After a while, your concentration fades, and your writing efficiency diminishes.

Finding a block of time at work is often difficult. So many interruptions exist: texts, phone calls, emails, and visitors. To make the writing process efficient for yourself, you should eliminate those interruptions. If allowed, you should shut the door, turn off the phone, mute the email messages, and focus on your document. You will find that absolute silence in your room is not necessary. White noise is okay. So is instrumental music. However, each interruption, no matter how short, will cost you at least ten minutes of writing time because it takes time to get back into the document—to find your place again and begin writing sentences that add to what you have already done.

If shutting your door is not an option, consider coming in early before others arrive. In writing the first edition of this book in the 1980s, I would arrive to Sandia National Laboratories at 6:00 a.m., sometimes earlier. Those first two hours were the most productive of the day. Another option is to stay late. Some writers, such as Agatha Christy, work best at night. Are Magnus Bruaset, one of my colleagues at Simula Research Lab in Norway, is a night owl. More than once, I have written him an email at 9.00 p.m. from the United States, only to receive a quick reply.

Some distractions are created, rather than imposed. Computer games, especially the game of bridge, pose a problem for me. If that game is on the computer, I feel a constant force tugging me away from my writing. Just a window away is a freshly dealt hand. After struggling to achieve a balance between work and play, I went cold turkey one day and deposited my bridge game into the trash.

Finally, you have to prepare yourself mentally for the task ahead. Scientific writing is hard work. It is not something that you can casually begin after a heavy meal or a glass of wine. Many scientists and engineers mistakenly think of professional writers as free spirits who write perhaps 2 days a week and play the other 5. In this imagined schedule, writers spend most of their time fishing, traveling, or going to bullfights. Actually, most professional writers are diligent workers. Hemingway, for instance, followed a schedule of writing for eight hours a day, 6 days a week. Stephen King writes 7 days a week, 365 days a year—yes, even Christmas [5]. No one expects you to have Stephen King's schedule but you need discipline.

Instead of worrying about the way that professional writers spend their leisure time, you should consider the way that professional writers spend their writing time. You should also study the styles of professional authors. To this end, do not choose writers from the eighteenth century whose language is outdated or writers such as Faulkner or Joyce whose styles are luxuriant. Rather, choose writers whose styles are crisp and straightforward. Richard Rhodes (*The Making of the Atomic Bomb*) is an excellent choice. So are Laura Hillenbrand (*Seabiscuit*) and Jon Krakauer (*Into Thin Air*).

## For long documents, draft at least one page a day

The next day, you first take care of the immediate tasks at work: your input to the *Quarterly Report* and an email to the professor from Ohio State. You leave work early and eat a light meal at home. You wash the dishes, put in a load of laundry, and go out for a slow run—something to clear your mind. You run out beyond the subdivision, out into farmland where you are surrounded by corn stalks and alfalfa rows. There is still daylight, and you are thinking about what you are going to write.

After you finish your run, you shower and drive back to the office. No one is there. It is almost seven o'clock. Somehow the place seems different. Maybe it is the stillness, or just the quiet. The only sound is the hum of the drinking fountain.

You sit at your desk with your spiral notebook of results in front of you. You are in the mood.

You turn on the computer and stare at the blank screen. You finger the keyboard but do not type anything. You are still thinking. The steady, expectant hum of the computer needles you. To break the hum, you dash off a title for your paper:

Additively Manufactured Gas Turbine Channel Surface
Roughness Measurements

Confusing, you think. Too many big words in a row. You highlight, hit delete, and try again.

Measurements of Surface Roughness
on Additively Manufactured Cooling Channels
in Gas Turbine Engines

That title captures the scope but you remember that your supervisor does not want to limit the audience to just those in gas turbine research. She also sees this work applying to small channels used to cool electronics. You cut the last phrase:

Measurements of Surface Roughness
on Additively Manufactured Cooling Channels

This title is not perfect but it is a start. The rest of the screen is blank. It stares back at you. Suddenly, you feel tired. You lean back in your chair and rub your eyes. You loathe first drafts. You would do almost anything instead of writing a first draft: fill out your taxes, clean the bathtub, and watch a stock car race on television.

Come on, you tell yourself. You have wasted enough time. You must write something down. An outline you think. That is what you were always taught. So, you write one

A. Introduction
B. Experiment
C. Computations
D. Conclusions

What about a summary You write “Summary” above “Introduction.” Your word processor automatically changes all of the letters. Now you look at your outline.

A. Summary
B. Introduction
C. Experiment
D. Computations
E. Conclusions

Not much help you think.

You decide to try something else. What is the point, you think, of writing the paper in one file only to paste in later to the conference's format file? So, from the conference's website, you download the file with the paper format. You open that file and insert your title into the text block for titles. The formatting file already has a section especially formatted as the Summary, and the section headings "Introduction," "Conclusion," "Acknowledgment," "Nomenclature," and "References." Moreover, all of these sections have placeholder text blocks for what you will write. You quickly add section headings and placeholder text blocks for "Review of Literature," "Methods," "Results," and "Discussion." You scan through the headings and placeholder text blocks of the paper. Now you are getting somewhere.

You start with the summary text block, but you remember that an informative summary is the last thing that you write. So, you skip down to the introduction. You start writing a sentence about how additive manufacturing began in the early 1990s, but then you stop. What is an introduction supposed to do? Introductions are supposed to prepare readers for what is ahead. How can you prepare someone for something ahead if you do not know what that something is? You put the "Introduction" page aside as well.

So far, things are not going well.

For some reason, you are restless. It is eight o'clock and you are hungry again. You go down the hall and get a Milky Way bar. You know that candy bars are bad for you but you are working hard tonight and deserve a treat. After you finish the Milky Way, you feel tired. You consider calling Hank to casually ask whether he watered the office plants today, although you know he has not. You have the hope that he might give you a preview on the upcoming series with St. Louis. Then, you think about going home and crawling into bed.

You have lost the mood.

Do not deceive yourself. The first draft of a document is difficult. In the first draft, you juggle your topic and your writing constraints with all three elements of style. What should you do to get through a first draft? The first thing you should do is take a few deep breaths and prepare yourself for the road ahead. If the document is long, you are not going to finish the draft in one sitting. If you do, chances are that the draft will not be any good. In writing a long document, you have to be realistic. It has taken you several months to do your work. Given that, significant time is also needed to finish the document—days in some cases, weeks in others.

In writing the first draft, the central question becomes, How do you get words onto paper? The answer is whatever it takes, short of plagiarism. Should you use an outline? Every English teacher in school told you to use one. Although that fact might make you suspicious, the answer is a qualified "yes." A strong outline is helpful (some would say essential) for long and complicated documents. A strong outline gives you a structure before you begin writing. That way, in your early drafts, you have to juggle only two elements of style—language and illustration.

To be effective, though, your outline must be strong. What makes for a strong outline? Detail. A strong outline not only lists your section headings but also your subsection headings, notes about each section, and any sentences or phrases that come to your mind. Outlines by professional writers usually do not look like the neat little ABCD things your English teachers put on the blackboard. Professional outlines, such as the one below, are long and spread out and above all, filled with the kinds of things that make it easy for you to write a first draft.

## *Outline*

### Measurements of Surface Roughness on Additively Manufactured Cooling Channels

#### Audience

The principal audience consists of engineers at gas turbine manufacturers. They have detailed knowledge about cooling channels in gas turbine engines but not about additive manufacturing. Some of these engineers are antagonistic to putting time and money into this research because they want to fund ideas that will have a quicker return on investment.

One secondary audience would be officials at the DOE and FAA. This audience, which has a general knowledge about gas turbine engines, is mainly concerned about what roadblocks exist to prevent cooling channels from being additively manufactured. Another secondary audience would be engineers in the electronics industry who are interested in using additively manufactured channels to cool electronics.

#### Introduction

Identity of research:

This report discusses effects of build direction on surface roughness in additively manufactured cooling channels. Initial background includes

(1) Recent advances in laser sintering—now we are able to additively manufacture metal alloys that can withstand high temperatures;
(2) Limitations on use of such parts but not parts that experience high stresses; and
(3) What else?

Reasons that research is important:

(1) One application in stationary hot portions of the turbine section of jet engines; another application in cooling of electronics.
(2) In such additively manufactured parts, engineers desire to incorporate complex designs that conventional manufacturing cannot produce.
(3) Using additive manufacturing offers the possibility of creating such designs.

Scope and Limitations:

(1) Laser power bed fusion, which is a specific type of three-dimensional printing, is the additive manufacturing technique to be considered.

(2) Variables in laser powder bed fusion that affect quality of a part: laser scan speed, layer thickness, powder metal, and build direction (consider adding a table here showing the variables). Limitation: this paper focuses on build direction.

(3) How the quality of an additively manufactured part is affected: geometric tolerance and surface roughness. In the literature review, reference your team's earlier paper on geometric tolerance.

Mapping of Paper

Review of Literature

.
.
.

Note that this outline has parts of sentences interspersed among the details. If you are writing an outline and suddenly come up with an idea for a sentence or transitional phrase, add that sentence or phrase to your outline. If not, you risk the chance of forgetting the sentence or phrase when you begin the first draft. What if someone else asks to see the outline? Would not all of these details and questions and sentence parts confuse them? The answer here is "yes," but the outline above is a working outline designed for you, not for others.

Granted, supervisors sometimes ask to see the outline of a document to check on your progress or whether your strategy for the document agrees with theirs. In such cases, you should create a clean version of your working outline in a separate file. As it turns out, your "cleaned-up" outline will often look like the table-of-contents outline that your English teacher taught you. Still, in drafting the document, you rely on your working outline. This working outline is solely for you. If you decide that your working outline will use green ink for illustration ideas and red ink for ongoing questions, so be it.

How do you actually move from the outline to the first draft? Let us first assume that you have a strong outline and that you are in the mood to write. Now, two basic approaches exist to writing the first draft: the rabbit's and the turtle's.

Rabbits hate first drafts. They despise juggling the constraints of writing with all the elements of style. So, in a first draft, they sprint. They write down anything and everything. Rabbits strap themselves in front of their computers and finish their drafts as quickly as possible. Unfortunately, their first drafts are horrendous, sometimes not much better than their outlines. Nonetheless, they have something. They have put their ideas into a document, and they are in a position to revise.

Turtles, on the other hand, are patient. Turtles accept the job before them and proceed methodically. A turtle will not write down a sentence unless it is perfect. In the first sitting, a turtle begins with one sentence and slowly builds on that sentence with another, and then another. In the second sitting, a turtle then goes back to the beginning and revises everything from the first sitting before adding onto the draft. For a turtle, it usually takes several sittings to finish a first draft of a longer document but the beginning and middle are smooth because those parts have been reworked so many times. Revision then entails looking at the document from an overall perspective and smoothing the ending.

Which type of writer should you be? The answer is whatever type works for you and your document. Actually, few professional writers are strictly rabbits or turtles. Most professional writers are a combination. If you become stuck in the first draft and your writing slows to a stop, you should become a rabbit so that you can finish. On the other hand, if you are working on a section that establishes the organization for the rest of the document, you should be a turtle. Otherwise, you might have to start over.

On which section of a paper should you begin writing? The introduction or the middle? This question is difficult. On the one hand, you psychologically need some kind of introduction before you can begin the middle. On the other hand, the middle is the easiest section to write first. My feeling is that you should be a rabbit on the first draft of your introduction and then write the middle and conclusion at your normal pace.

After finishing the conclusion, you should go back and rewrite the introduction.

George Whitesides, the prolific Harvard chemist, has written an excellent short article about the process for the team writing of a research paper [6]. In the article, Whitesides argues that the lead author should begin with the hypothesis and then skip to the results, once those start coming in. In addition, the lead author should not write anything else in the paper until the research team agrees on the hypothesis and the results. The reasoning is that writing in other sections could be wasted effort if the authors do not agree on those two cornerstones of the paper. This advice could easily apply to all types of collaborative writing by engineers and scientists. In other words, you agree upon the principal story of the document before you expend time drafting all the different sections.

A common question concerns when to write the summary (or abstract). The answer depends on the type of summary you are writing. A descriptive summary you can write early, even before the work is finished, but an informative summary you want to write last. One good way to draft the informative summary is to wait until you have a polished draft of the text. At that point, you can highlight the most important sentences (and illustrations in the case of a report). With the addition of sentence transitions and needed background, these highlighted sentences can serve as a first draft for the informative summary.

The key to writing first drafts is momentum. Because scientific writing is so textured (because each sentence depends so much on the ones around it), you need to sustain momentum during your first draft. Otherwise, you will lose your train of thought. Success in scientific writing does not depend on a single burst of inspiration but the patient building of one sentence upon another.

So how do you sustain momentum? Well, given below are a few habits that you can borrow from professional writers.

*First, set realistic goals*. How large a goal you set depends on how much of a rabbit or turtle you are. If you are a rabbit, then a realistic goal for a single sitting might be three pages. If you are a turtle, a realistic goal might be one page. Realistic goals are important. Psychologically, you want to end each sitting with a feeling of accomplishment. As Richard Rhodes, the Pulitzer Prize winner, said: “A page a day is a book a year” [7]. If you are a researcher, that advice could become a page a day is a journal paper in a month (if your discipline’s papers are long) or in a week (if your discipline’s papers are short). If you are a graduate student, the advice could become a page a day is a thesis in a semester. The beauty of this advice is that a page a day is your minimum. On some days, you will write more. However, writing that page each day maintains your momentum.

*Second, end your sittings by writing into the next section.* By writing into the next section at the end of each day, you will find it easier to start writing the next time you sit down. In other words, the next day, you will have a little momentum rather than a blank page. The fiction writer André Dubus claimed that when he ended a sitting, it was mid-sentence, mid-thought [8].

*Third, watch what you eat.* Writing makes you restless, which makes you hungry. One way to counteract that is to sip on a glass of water or a cup of tea or coffee while you write. If you must eat, do not eat foods that will make you sleepy. Also, avoid foods that require two hands such as bananas (you have to peel them). You want something of the document that you can reach with one hand. Celery and carrot sticks are probably the best but you can munch on them for only so long. Trail mix is a possibility. So is light popcorn. Still, the best setting is without food—just a glass of water or cup of tea.

*Finally, when you finish a draft, store it on your computer under a separate file name.* Having a clean version that you can print out at any time gives you a psychological advantage when you start revising the original. In addition, during revision, you will not fret about being caught empty-handed in case your supervisor needs a clean draft right away.

How do you write a first draft when you are pressed for time? No real shortcuts exist in writing a first draft outside of abandoning your colleagues and family and locking yourself in a room. Interestingly, when you are pressed for time, the one part of the writing process that you do not want to cut short is the first draft. If anything, you should spend extra time on your first draft because you cannot afford to choose a structure that is inappropriate. Otherwise, you could have the document in pieces on your desk when the deadline strikes.

A common question is what to do about writer's block. Well, writer's block is one of those bits of folklore that many engineers and scientists talk about, especially when they have problems writing. "The words just aren't flowing," they will say. "I must have writer's block." Well, the words rarely "flow" for anyone, professional writers included. Most professional writers struggle the same way you do. They struggle with the paragraphs, sentences, and words. So what is the source of this term "writer's block"? When writing a document, certain things, besides distractions, can cause you to stop.

First, you cannot think of the right word. Not having the right word happens to everyone. Many times, the word is on the tip of your tongue. In such a case, a possible solution is to pull out a dictionary and spend two or three minutes looking. If you do not find the word after three minutes, write down the name of your favorite baseball player (mine is *Clemente*) and keep going. Your subconscious will think of the right word later.

A second source for writer's block is that you cannot find the sentences to express an idea. In this situation, chances are that you have not quite grasped that idea yet. A possible solution is to skip two lines and keep writing. Let the idea simmer. Maybe you can think about the idea on your next run, walk, or other exercise activity. In truth, although the methodical building of one sentence onto another is the main ingredient for success in writing scientific documents, you often need a small burst of inspiration to discover how to phrase a complex idea, how to connect two sentences, or how best to graph the data. Exercise fosters those bursts.

Yet, a third source for writer's block is that you hear voices. When many engineers and scientists sit down to write, they hear voices, critical voices: a professor, their department manager, the theorist down the hall who complains bitterly about everyone's writing but does not write so well himself. These voices inhibit you—your hands freeze up on the keyboard. A possible solution is to put on your favorite classical music and turn up the volume until it drowns the voices. Listening to Bach's *Brandenburg Concertos* works well for me.

In scientific writing, there really is no such thing as writer's block. Once you have done the work, the ideas are there. Ninety-five percent of the actual writing of the document is the methodical crafting of one idea upon another. For engineers and scientists, the real block occurs when the ideas will not come but that block is a block in science, not in writing.

## Revising allows writers who struggle to create documents that excel

Revision is the key to strong scientific writing. Revision is the difference between a title such as

Measurements of Surface Roughness
of Additively Manufactured Cooling Channels

and a title such as

Effect of Build Direction on Surface Roughness
of Additively Manufactured Cooling Channels

For the work described in this chapter, the second title is more precise. You were not just measuring the surface roughness of additively manufactured channels. Rather, you were testing the effect of one manufacturing variable (build direction) on that roughness. The fact that you made roughness measurements in determining the effects is a secondary detail best reserved for the document. This difference in scope is important but this difference might not have been apparent when you were staring at the blank computer screen of a first draft.

In your first draft, you have to juggle too many elements of style to give proper attention to a single one. Revision gives you the luxury of focusing on the parallel structure of your headings, the connections between sentences, or the clarity of your illustrations. Engineers and scientists, perhaps more than other professionals, understand the importance of revision. Experiments depend on trial and error. Computations require many iterations to arrive at solutions. The design process follows the testing of a series of prototypes. Just as revision is important in science, so is revision important in scientific writing.

Many engineers and scientists hold the misconception that great writers do not have to revise. These engineers and scientists mistakenly assume that great writers effortlessly write down their thoughts in a prose that needs no reworking. Perhaps for some writers, such as D. H. Lawrence, the first drafts could go straight to press but such writers are in the small minority. For every D. H. Lawrence, you can find at least ten writers who were constant revisers: Leo Tolstoy, Dorothy Parker, Ernest Hemingway, Susan Sontag, Ralph Ellison, Carolyn Chute, Elmore Leonhard, Flannery O'Connor, Vladimir Nabokov, and Truman Capote. As the opening quotation for Lesson 7 stated, Hermann Helmholtz claimed to have rewritten each of his papers four or five times—with significant changes in each draft—before getting the paper to a state that satisfied him [9].

The short story writer Raymond Carver said that he never took fewer than ten drafts to finish a story [10]. If great writers such as Raymond Carver required ten drafts to smooth their writing, just think how many revisions the rest of us need. In my own writing, I average about five pages a day. Unfortunately, they are all the same page. It is unusual for me to have a sentence written during the first draft make it to the final draft unchanged. For most of us, the key to successful writing lies in working hard on our revisions, not in conjuring magic on our first drafts.

So what does revision entail? Before you begin revising a document, you should obtain some distance from it. After finishing a first draft, spend the rest of the day working on another project. Better still, hike in the mountains or have a night on the town. You need a good night's sleep after your first draft before you can effectively revise. Things have to settle. During this time, ideas for changes will likely come to you. Write these ideas down but do not go back to your draft.

Also, to become a successful reviser, you have to become a good reader. How do you become a good reader? One way is to listen to other good readers. Just as no two people write the same way, no two people read the same way. Some people are particularly attuned to language. Others are sensitive to structure. Listening to good readers review a document will help you strengthen your own reading. A second way to become a good reader is to practice. Work hard on your critiques of other people's documents. In doing so, be specific. Do not just say that something is unclear. Think about why you became confused. In addition, do not mark just the weaknesses in a document; also mark the aspects that you find successful. You will find that telling someone what is strong in a document is as challenging as pointing out the aspects that are weak. How quickly you mature as a writer will depend on how quickly you mature as a reader.

What is the best method of revising? No definitive answer exists. Still, many successful writers adopt common techniques:

*First, change the look of your document when you revise*. If you drafted your document on a computer, try revising on a hard copy. Likewise, if you drafted your document in your office, try revising the document in the library or conference room. In other words, make the revision process different from the drafting process.

*Second, try to work through large chunks in each sitting.* Revising large sections of your document in single sittings makes your document smoother. With this approach, you will better see gaps in logic and faults in structure. During your first or second revision, you will write much because you will fill in large gaps and repair sections that do not work. As with the first draft, set realistic goals for yourself on each sitting. In later revisions, you should have fewer and fewer corrections, and therefore you can read larger chunks. Ideally, you would like to reach the point where you can read through the entire document in a single sitting or a single day.

*Third, get a good night's sleep between each revision.* Avoid making multiple passes through a large document on the same day. If you read a document or section multiple times, it is easy to go stir-crazy and start changing things for no reason. How many times should you revise a document? For your documents to sing, you should revise until you are nitpicking over language: a word here, a comma there. In one of your later drafts, read the most important sections aloud. You will be surprised at how many things your ear will catch. Although you want to obtain distance between drafts, you do not want too much distance. Allowing a draft to sit on a desk for months certainly gives you distance from the draft but also saps the momentum from the project. After such a break, you will feel compelled to update the science in the document, which will make the revision seem more like a first draft.

*Finally, solicit criticism of your writing*. Soliciting criticism is an excellent way to revise. No matter how you try to separate yourself from your work, you will take certain things for granted. For instance, in your report about advanced manufacturing of cooling channels, maybe you forgot to mention the composition of your metal alloy in the summary. That detail would be an easy oversight for someone engrossed in the work but one that a fresh reader would readily catch. If you are going to solicit criticism, you should be willing to make changes. This caution might sound silly but you would not believe how many times someone has asked me to review a document and then been appalled when I suggested revisions.

Once you solicit criticism of your writing, you should be prepared to accept that criticism. Do not be defensive when people whom you respect speak harshly about your writing.

They are not attacking you. Actually, when people appear agitated about your writing, it is a compliment of sorts. It means that they are frustrated—they genuinely want to understand your work but portions of your writing are not effectively informing or persuading. If your critics are indifferent, that would be the occasion to be upset.

How do you know when to incorporate criticism and when to dismiss it? This question is difficult. You should not give a rubber stamp to every suggested change, even if the suggestions come from a good critiquer. Rather, you should weigh all criticisms. If you think a criticism is valid, incorporate it. If you think a criticism is odd, at least mull it over. Maybe a deeper problem occurred within that section or paragraph that the critic could not articulate.

Do not seek too many critics. You will become confused. On a 5-year plan for one of its solar programs, the Department of Energy decided that everyone in the program should review the document. In effect, the Department of Energy wanted all the readers to become the writers. The result was chaos. Because the report was general in its original scope, the two hundred critiques served only to push the document into two hundred different directions. For several years, the Department of Energy haggled over draft after draft of that report, wasting thousands of person-hours, before finally scrapping the whole document.

This example raises the question of how you should approach collaboration on a document. First, you should put aside the ill-fated strategy that many undergraduate design teams adopt of having each member write equal portions of the document. This strategy highlights the disadvantages of collaboration without leveraging the advantages. In the end, this strategy usually produces a document broken into three or four disjointed portions, with each portion having its own style and with the whole document lacking focus, transitions, and needed background.

A much better strategy is to seize the advantages of collaboration and mitigate the disadvantages. The principal advantage of collaboration is that working in a group broadens the range of ideas that the document can incorporate. Collaborative writing also allows the group to draw from the various writing strengths of the members, such as one person's ability to see the big picture or another's ability to design effective graphs or yet another's ability as a proofreader. The principal disadvantage of collaborative writing is an inherent lack of continuity. With multiple writers contributing to the text, you can have inconsistencies in language, particularly in word choices, average sentence lengths, and degrees of sentence variety. In an ideal collaboration, you optimize the advantages and minimize the disadvantages.

One way to seize the advantages of collaboration and mitigate the disadvantages is to solicit everyone's ideas and strategies at the outlining stage but then have one person be the lead writer for the project to ensure that the document maintains continuity. In choosing this lead writer, the team should look to someone who works ahead of schedule as opposed to someone who finishes things at the last minute. In the drafting stage, this lead writer might call on other members, depending on their expertise, to draft a specific paragraph or two, but that lead writer should integrate all those pieces into the whole. Moreover, the other team members might also contribute to the draft in specific ways, such as creating the graphs or tables. Finally, the other team members need to be ready to revise when the lead writer issues the draft.

In the revision stage, the group would again have input. For this collaborative scheme to work, the group should respect the writing ability of the lead writer, and the lead writer should respect the editing comments of the group. This scheme is not the only way to achieve a successful collaboration. More important perhaps than the collaboration scheme is the interaction of personalities. Each person in the group should realize that the final product will not read exactly as he or she would desire. In other words, everyone in the group has to bend. That flexibility does not mean that group members should tolerate illogical strategies or discontinuous language but that group members should accept that multiple ways exist for writing decisions such as how to organize a section or how to achieve sentence variety.

What happens to revision if you are on a tight schedule? In many projects, the time allotted for the writing is short. You might have begun with good intentions (for instance, scheduling a month to write the report) but then you lost 10 days in February because of a late shipment, 3 days in April because of a sick technician, and another 2 days in June because the computers were down. The month that you scheduled for writing has slipped to 1 week. So what do you do? Well, as stated in the previous section, you should spend enough time on your first draft to secure a structure that works. Then, you have to revise efficiently.

Revising a document is much the same as leveling a piece of land. In your first couple of revisions, you wield a pick for groundbreaking as you edit on the section and subsection level. Then, in your remaining revisions, you use a rake for smoothing, as you progress from rearranging paragraphs to polishing sentences to nitpicking over words. When time is short, you cannot afford to revamp the structure in your last couple of revisions. If you do, you might improve the overall grade a little but you will unsettle the soil much. Also, when pressed for time, you should reduce the time between revisions. In this reduction, you should find some absorbing activity such as running or walking or perhaps a light meal away from the office to separate yourself from the previous draft.

At some point in the process, though, you have to say "enough"—enough to outside suggestions and enough to revisions. You have to decide that your document is successful and then you have to finish it.

Many scientists and engineers think that perfection can be achieved in writing. Except perhaps for the Ten Commandments, no perfection exists in writing (and even the Ten Commandments suffered revision between Exodus and Deuteronomy). Words are not exact substitutes for thoughts. Inevitably, on each reading, you will want to change something: a sentence that does not sound correct on Wednesday; another sentence that does not sound correct on Thursday.

Although no perfection exists in writing, there is success. For your sanity, you have to find a point at which you stop drafting. Evan Connell once said that he knew he was finished with a short story when he found himself going through it and taking out commas, and then going through it again and putting commas back in the same places [11]. The documentation of strong science deserves a similar amount of care. Although you cannot achieve perfection in your writing, you should still strive for it. Strive for perfection but be content with success. One of the beauties of writing is that you do not stop learning. With each document, you improve your craft.

## Finishing focuses on correcting, not on improving

It is two o'clock in the morning. Your paper has gone through sign-off, and you have finished proofreading it for what seems like the fifteenth time. You are exhausted but you correct the last two typos and print out the final copy. No one is in the office. You wish someone was—anyone. They would not have to read your paper, just admire the stack of pages. You would tell them how smooth the writing was, maybe read aloud the title and summary.

Finishing a document is significantly different from revising a document. In the finishing stage, you are not reading with the mindset of how to improve the document. Rather, you are reading with the mindset of what has to be corrected.

As with revising a document, finishing a large document taxes you. By your final draft, many of the words seem dead on the page. You do not actually read them. You only see yourself reading them. Although the final proofread of a manuscript can seem tedious, you should not let up. A small mistake such as a missing word in a heading or first sentence can unsettle your readers and undercut your work. Finishing a document is much the same as finishing a baseball game. Some teams, when they are ahead, let up during the last few innings. They play sloppily, sometimes so sloppily that they lose their lead. Some writers are the same way. They work hard on the first few drafts but then let up on the final draft, allowing typos to pull down the work.

Should you rely on a computer spell-checker to find those typos? “Rely” is the wrong word here. Spell-checkers are wonderful for catching misspellings such as “recieve” instead of “receive.” Spell-checkers even notice if you repeat a word such as “in the the chamber.” However, spell-checkers miss a number of misspellings, such as when the misspelling is another word (“then” rather than “than”). Spell-checkers also do not catch errors such as missing words (“in chamber” rather than “in the chamber”). For these kinds of errors, you need a person rather than a computer. In other words, you should use a spell-checker but that spell-checker should supplement, rather than replace, your own careful proofreading.

Besides being taxing, the completion of a large document is often thankless. By the time your document appears in print and people comment on it, you have lost feelings for the writing. More than likely, you are focused on your next project. Such is the way the writing process goes. Do not expect satisfaction in your writing to come from other people. If you do, you will be disappointed. Satisfaction in your writing has to come from within. It is the beauty of a well-formatted document, the peace of having given a permanence to a project, and the realization that others will benefit from your efforts.

You make a final copy of your paper for your supervisor and upload the file to the conference website. You are euphoric and exhausted at the same time. It is over. You leave the lab. The night is cool, and the moon glimmers behind some thin clouds. You think you hear opera. You get in your car—a maroon Impala with a bad muffler—and drive past the open fields tinted purple and blue by the night. At a stop sign, your muffler wakes a neighborhood dog. You wish that you could wake everyone and tell them what you have done.

You are tired but you cannot go to bed—not just yet. You need some kind of celebration. Bangkok Garden is closed but the Diner is still open. You will order a portabella burger with a side of sweet potato fries and read the sports pages. The Pirates are headed for the playoffs, and this time you have a good feeling that they are going to win.

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# Conclusion

*We are all apprentices of a craft where no one becomes a master* [1].

—Ernest Hemingway

To succeed in writing a scientific document, you first need valuable content. Although not every data point or calculation has to be finished, you should have worthwhile findings or ideas to convey. Second, you should know the audience, purpose, and occasion. In particular, you should understand who your audience is, what they know about your content, and why they are reading. In addition, you should be clear about your purpose for the document—in particular, the effect that you want the document to have on the audience. In scientific writing, the purpose can range from simply informing the audience, such as in a set of instructions, to securing funding from the audience, such as in a proposal. Accounting for the document's occasion is important as well, particularly the length and format.

At the sentence level, you have to be able to cast each idea into a clear and precise sentence. To do so, you should heed Einstein's advice: "Keep things as simple as possible, yet no simpler" [2]. Being clear also means avoiding ambiguity. In scientific writing, two of the most common sources of ambiguities arise from unclear pronouns such as the standalone *this* and from missing commas, particularly after introductory phrases and clauses. Besides being precise and clear in your sentences, you also want to sustain the energy of the writing.



M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9

For verbs, select the natural voice for verbs, which most often is active. For nouns, either you should select concrete nouns or you should anchor abstract nouns in examples. In addition, because concise writing is energetic writing, eliminate needless words.

To connect your sentences into paragraphs, begin each new sentence with wording that makes a solid connection to the previous sentence. Connecting with the previous sentence requires that you have an assortment of transitional words and phrases such as *therefore*, *however*, *for example*, and *for that reason*. Connecting with the previous sentence also requires that you can select from an array of sentence openers such as dependent clauses, infinitive phrases, and participial phrases.

At the section level, you should begin with what is familiar before moving to what is new. In addition, early in longer sections, you should map the direction of the section. At the section level, you will also want to incorporate equations and illustrations. While an equation is part of the paragraph, an illustration is not. Nonetheless, you want to integrate illustrations with the text by introducing each illustration by name, explaining the illustration in the text, and writing a descriptive heading for each table and a descriptive caption for each figure.

The sections you then arrange into documents. Beginning each document is a title that communicates the scientific area to which the document belongs and, if possible, that separates that document from all other documents in that area. For longer documents, you will also want to include a summary that conveys the essence of the document. The main part of the document's text consists of an introduction, a middle, and a conclusion. The introduction prepares the audience for the middle by defining the scope and limitations, showing why the content is worth reading, providing essential background, and mapping the document. The middle tells the story of the work, and the conclusion summarizes the most important details and provides a future perspective. Longer documents also contain appendices that provide both secondary information for primary readers and primary information for secondary readers.

Just organizing the details in a logical way is not enough. You also have to emphasize the most important details. To achieve proper emphasis, you can repeat important details. In addition, you can place important details in valuable positions, such as the beginnings of paragraphs and sections, the endings of paragraphs and sections, and within illustrations. Where text borders white space is where you achieve emphasis.

For special documents such as emails, the organization is the same as for the main text of papers and reports, but brevity of the document usually collapses that organization into one to four paragraphs. Also, the speed at which audiences read emails affects the language. Typically, in emails, you have shorter sentences and paragraphs than you do in papers or reports. In addition, the focus on one person or one type of audience allows for the use of *you,* which should balance with your natural use of *I.*

Instructions are another type of document that requires special attention. Namely, instructions call on you to show the audience how to perform a technical process. Because the focus is on *how,* the sentences and paragraphs are shorter in instructions than in scientific papers or reports. Also, because the audience is an active participant in the process, instructional documents use the pronoun *you.* In addition, instructions often place steps in vertical lists so that each step is separated by white space. That way, the reader can read a step, turn and perform the step, and then quickly find her or his place in the document.

Yet another special document is a proposal, which is a plan to address a problem. In science and engineering, proposals move the money. Because the stakes are high, proposals are competitive. For that reason, it is not enough that your proposal communicates an understanding of your ideas to the reader. Your proposal also has to persuade the reader to fund your plan. The main text of proposals follows a specific organization: first a description of the problem, followed by the plan to address that problem. Interwoven through the proposal is an argument for why your team should be funded. This book identified three best practices in crafting proposals: sticking the beginning, emphasizing the assertions of the proposal's main argument, and showing the proposal's plan in a graphic.

Success in scientific writing is not all about style. Process is important, too. Especially in writing long documents, engineers and scientists need to become efficient at getting words onto paper. In their writing, most professional authors follow the same four stages: preparing, drafting, revising, and finishing. Much of the preparation stage involves thinking, planning your writing blocks, and gathering sources, data, and images. The second stage of the process is drafting, which might be the most difficult stage, especially with long documents. For this stage, the longer the document is, the more valuable an outline becomes. Also important becomes momentum. It is better to write at least one page each day [3], as opposed to having sporadic spurts of three pages on Monday and then four pages the next Thursday. Although many people complain about revising, this third stage might be the most important. Revision allows an average writer (such as me) to craft a quality document. As with drafting, revising requires a regiment. For instance, one strategy is that as you march through the document on the revision, you rework the weak sentences and paragraphs. By the end of the day, though, you reassemble the improved document. The last stage is finishing, which is a hustle stage. Whereas you seek to improve the document as much as possible during revision, you seek to correct only the errors in the finishing stage. At some point, you have to push the document out the door so that you can move onto other things. In sum, success as a scientific writer does not depend on a single burst of inspiration, but the patient building of one idea upon another,

Your education as a scientific writer does not end by finishing the reading of this book, attending a professional workshop, or completing a college course. Each year, you will learn new strategies. Moreover, if you go through long periods in which you do not write, you will have to relearn much about writing when you finally do start another document. What Hemingway said about fiction writing in this chapter's quotation applies to scientific writing as well. As writers, we continue to learn through our careers.

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# Grammar: Recognizing What a Sentence Is and Is Not

*Bad grammar produces bad sentences* [1].

—Stephen King

Your success in scientific writing hinges on you being able to write effective sentences. Achieving this goal calls on you first to recognize what a sentence is and what it is not. This recognition is the most important part of *grammar.*

Not understanding what defines a sentence leads to major grammatical errors such as a fragment and run-on sentence. Such errors not only cause the audience to reread the passage, but also undermine the author's credibility. For instance, a common type of run-on sentence occurs in the example below:

Mistake: No cure for Alzheimer's exists, however, scientists have isolated the gene that causes it

This structure is not an accepted sentence in professional writing. Although you can quickly find this structure by perusing websites and message boards, you will not find this structure in *Nature, The Wall Street Journal*, or any well-edited publication. Ironically, this mistake is readily corrected in several ways:


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9

Correction: No cure for Alzheimer's exists. However, scientists have isolated the gene that causes it.
Correction: No cure for Alzheimer's exists; however, scientists have isolated the gene that causes it.
Correction: No cure for Alzheimer's exists, but scientists have isolated the gene that causes it.
Correction: Although no cure for Alzheimer's exists, scientists have isolated the gene that causes it.

Although each of these corrections requires only a small change to the wording or punctuation, the mistake itself reveals a fundamental misunderstanding of what a sentence is. Because of a recent educational movement in the United States that decried the formal teaching of grammar [2], many U.S. engineers and scientists do not recognize this error. However, many other engineers and scientists still do. For such readers, the mistake is egregious. In a proposal, such a writing mistake can cause reviewers to question the author's education. In a job application letter, such a mistake often moves the application to the reject pile.

This appendix discusses how to avoid run-on sentences and other serious grammatical mistakes in scientific writing. In addition, this appendix separates these serious grammatical mistakes from grammatical constructions that some engineers and scientists tout as being important, but that most professional writers and editors dismiss as inconsequential.

## A sentence contains a subject and a verb, and gives a complete thought

In scientific writing, the sentence is the fundamental unit of communication. For instance, in a professional email or letter, the audience expects every group of words after the greeting and before the salutation to be a sentence. In a paper or report, the same is true for each word group, other than the title, headings, and captions.

Given the importance of sentences in professional writing, this appendix introduces and defines what is and is not a sentence. Where needed, this appendix uses grammatical terms. To understand these terms, though, you need not recall an academic definition. Rather, a practical definition, such as supplied by the Glossary, is fine.

So what is a sentence? As Mrs. Hutton explained to my classmates and me so many years ago, a sentence is a group of words with a subject and a verb that gives a complete thought. For that reason, the following word groups are sentences:

On its maiden voyage, the Titanic grazed an iceberg.
The collision created a long gash in the ship's hull.
Within four hours, the ship, which many had considered unsinkable, **sank**.

Although the subject for each of these three sentences is simply a noun, the subjects in many sentences are not so easy to identify. For example, consider the subject of the following sentence:

Striding at twice its body length allows the cheetah to reach high speeds.

In this sentence, the subject is actually the verb phrase "Striding at twice its body length." As discussed in Lesson 5, such a verb phrase has a special name: gerundial phrase. Another type of sentence that has an unusual subject is a command, which often appears in instructions:

Approach the drugged hippo from the rear. *(understood subject: you)*

Mrs. Hutton's definition of a sentence can also reveal what is not a sentence. For example, applying the definition reveals that the following word groups are not sentences:

| | |
|---|---|
| Needs half an hour after a chase to catch its breath before eating. | *(no subject)* |
| Examples of common prey being impalas and small antelope. | *(no verb)* |
| Because the cheetah expended much energy in the chase. | *(not a complete thought)* |

These word groups are called fragments and are not acceptable substitutes for sentences in professional writing. Note that the last word group would be a sentence if the word *because* were removed.

The cheetah expended much energy in the chase.

## Although many grammatical errors unsettle and distract readers, others are cosmetic

Not all grammatical errors strike audiences the same way. Some errors unsettle many readers, while some grammatical errors go unnoticed by most readers. To reflect the severity of a mistake, I have included different colored bullets:

● an error that unsettles readers
● an error that distracts readers
○ either not an error or a cosmetic issue

As indicated, the severity of an error depends on how much the error affects those readers. The worst category of errors would be an error such as a run-on (●), which unsettles readers in engineering and science to the point of them losing confidence in the author. With such an error, the audience might even question the author's education. A second category of errors would be an error such as faulty parallelism in a list (●). Although such an error distracts most readers and likely causes them to reread the sentence, readers will likely attribute the mistake to a proofreading oversight as opposed to a lack of understanding of basic grammar.

Yet a third category of errors would be an issue such as a split infinitive (○), which most editors and professional authors do not always consider to be an error. Such issues are often akin to wearing a tuxedo when a simple coat and tie is sufficient. Nonetheless, in your career, you will likely run into a manager or reviewer who expects you to follow these tuxedo rules. As Fowler states, some people "would sooner have their eyes gouged than split an infinitive" [3]. As a writer, you have two choices: (1) break the rule and ignore what the tuxedo critic thinks, or (2) work around the rule to appease the tuxedo critic. As an author, I generally avoid writing split infinitives so as not to upset the temperamental few who care about such things. As an editor (or reviewer), though, I usually let the practice pass because a split infinitive is such a tiny fish, compared with the much larger fish that usually reside in a document.

As you might suspect, the rankings of errors in this appendix as well as in Appendix B and Appendix C are not universal because not everyone responds to errors in the same way. In assessing the amount of distraction, I have tried to side with the majority of language experts, including William Strunk and E. B. White [4], H. M. Fowler [3], Theodore Bernstein [5], William Sabin [6], Lynne Truss [7], and Patricia O'Connor [8]. Although the assessments in these appendices are by no means universal, these rankings do provide you a guide for deciding how much energy to devote to learning a rule as a writer or advocating a change as an editor.

One common question that arises in my writing workshops concerns reliance on a computer's checker for grammar, punctuation, and usage. As with a computer's spell-checker, the checker for grammar, punctuation, and usage can act as an advisor for you, but cannot do the job alone. For instance, such a checker can find certain mistakes such as subject–verb disagreements, but not others such as misplaced modifiers. In the end, you must decide whether the sentence is correct.

***because*, beginning sentences with (○)** Beginning a sentence with *because* is not an error. In fact, given the importance of answering the question *why* in scientific writing, a dependent clause starting with *because* is an important sentence opener for engineers and scientists. One caveat is that since a clause beginning with *because* is dependent, the author must also include an independent clause to complete the sentence.

**comma splice** (see **run-on)**

**dangling modifier** (see **misplaced modifier)**

**conjunction to begin a sentence (●)** Coordinating conjunctions, such as *and*, *but,* and *or,* are powerful words that connect words, phrases, and clauses. Is it proper to begin sentences with conjunctions? Although most scientific journals frown on this usage, many respected newspapers, including *The Wall Street Journal,* allow it on occasion. Still, I side with most scientific journals. An easy way to sidestep the fray is to replace the *And* at the beginning of the sentence with *Also* or *In addition* followed by a comma. Likewise, replace the *But* at the beginning of the sentence with *However* or *Conversely* followed by a comma.

**fragments (●)** While sentence fragments are accepted in headings, illustration titles, and informal writing such as advertisements, fragments are not accepted in the text of formal writing.

***however*, beginning sentences with (○)** Beginning a sentence with *however* is accepted by almost all editors:

> After a long chase, the cheetah caught and killed the impala. However, hyenas ate the prey while the cheetah recovered its breath.

Note, though, that some editors argue that placing *however* a little later in the sentence is usually more graceful: "Hyenas, however, ate prey while the cheetah recovered its breath."

**misplaced modifier** (●) Have modifiers point to the words that they modify. Failure to follow this rule can cause ambiguities. In the example below, the misplaced modifier appears in italics.

Mistake: *Shooting at speeds of 100 mph*, the technicians tested the solar mirrors for hailstone damage.

Who or what was "shooting at 100 mph"?

Correction: To test for mirror damage, the technicians fired hail-stones at 100 mph onto the solar mirrors.

**parallelism, faulty** (●) In a list, present the items in a parallel fashion. In other words, if your first slice of pie is apple, then readers expect the remaining slices to be apple:

Mistake: Animals in contact with the oil can develop rashes, sores, and may leave the area.

Correction: Animals in contact with the oil can develop rashes, sores, and wandering tendencies. *(grammatically correct, but oddly worded)*

Correction: Animals in contact with the oil not only can develop rashes and sores, but also may leave the area.

Parallelism is often lost in conjunction pairs (called correlative conjunctions) such as *either…or*, *neither…nor*, and *not only…but also.* Such conjunction pairs require that what wording appears after the first conjunction be parallel with what appears after the second.

| | |
|---|---|
| Mistake: | Our goal is either to predict or measure the speed. |
| Correction: | Our goal is either to predict or to measure the speed |

**preposition to end a sentence** (○) In many cases, eliminating the preposition from the end of a sentence improves the sentence by tightening it. In other cases, not having a preposition at the end convolutes the sentence, as in the following sarcastic remark that is often attributed to Winston Churchill: "Ending a sentence with a preposition is something up with which I will not put" [9]. As an author, I tend to avoid the practice so as not to ruffle feathers, but as an editor, other than cutting the last word if it is unneeded, I usually ignore the practice and save my comments for larger issues.

**run-on sentence** (●) Sentences are the fundamental units of expression in scientific documents. Readers of professional writing expect authors to write in sentences. When a sentence runs on, readers often lose their place in the paragraph. They also lose confidence in the author.

The most common type of run-on sentence occurs when the writer tries to use an adverb such as *however*, *otherwise*, or *therefore* to join two independent clauses:

> All of the wolves survived the rugged winter, however, the bitter cold and lack of food weakened many in the pack.

This group of words is a run-on. In this case, two sentences were joined incorrectly by a comma and the adverb "however." Several ways exist to correct the error:

> All of the wolves survived the rugged winter. However, the bitter cold and lack of food weakened many in the pack. (*rewritten as two sentences*)

> All of the wolves survived the rugged winter; however, the bitter cold and lack of food weakened many in the pack. (*comma replaced with semicolon*)

> All of the wolves survived the rugged winter, but the bitter cold and lack of food weakened many in the pack. (*adverb replaced with conjunction*)

> Although all of the wolves survived the rugged winter, the bitter cold and lack of food weakened many in the pack. (*first independent clauses made dependent*)

Of the four proper corrections, the last is the most sophisticated because from the first word, the audience knows that the sentence is headed in one direction, but will turn back before the sentence's end.

**split infinitive** (○) *To measure quickly* or *to quickly measure,* that is the question—whether it is an improvement to keep the infinitive together or to allow a single adverb to slide between. Language experts from the seventeenth century, striving to make English parallel with Latin, decided that it was important for infinitives to remain unbroken. Language experts today have decided that it is not (unless the author were to insert more than one word between the *to* and the verb). While keeping the infinitive together does improve the sound of some sentences, this issue is not nearly as important as others. Besides, as Bernstein writes, one would be hard-pressed to rewrite a split infinitive such as "to almost double production" [5].

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Appendix B

# Punctuation: Helping Readers Navigate Your Sentences

*Punctuation marks are the traffic signs and signals placed along the reader's road* [1].

—Theodore Bernstein

As Bernstein states, punctuation marks help readers navigate sentences. A mistake in punctuation, such as a missing comma, can force the audience to reread the sentence to gather the intended meaning. Even worse, some mistakes can lead to ambiguity. Presented here are the rules and guidelines for punctuation that are most important in scientific writing.

**The Period**. The period is the most powerful piece of punctuation. In effect, the period is a stop sign. In many scientific documents, periods do not occur often enough. In other words, too many sentences ramble, taxing the reader's concentration:

> For temperatures above 1100 K, the four fuels examined had about the same ignition delay where the ignition delay was defined as the time to recover the pressure loss from fuel evaporation, in spite of the large variations in ignition delay among the four fuels at lower temperatures.

Although this sentence is grammatically correct, this sentence tries to convey too many ideas. Clarity demands breaking this sentence into two smaller ones, each conveying one main idea.

> Ignition delay is the time required to recover the pressure loss from fuel evaporation. Despite the large variations in ignition delay at lower temperatures, the four fuels had about the same ignition delay for temperatures above 1100 K.


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9

Although you should generously use periods to apportion your ideas into separate sentences, you should avoid using periods to abbreviate. When used in abbreviations, periods slow the reading:

> Figure 1.1 shows a gamma-ray line, i.e., radiation at a single gamma-ray energy level, that theorists had predicted would result from N. Cygni.

This sentence is stilted. When the format allows, challenge wasteful uses of periods and cut needless abbreviation to make smoother sentences.

> Figure 1-1 shows a gamma-ray line (radiation at a single gamma-ray energy level) that theorists had predicted would result from Nova Cyngi.

**The Comma**. Whereas periods are stop signs in sentences, commas serve as yield signs. Just as traffic engineers have leeway on whether to place yield signs in certain situations, so too do authors have flexibility with certain commas. However, some authors go too far. These authors use commas at the slightest suggestion of a pause. The result is that readers must wade through each sentence.

> Although many warnings, from governments, have been issued about acquired immunodeficiency syndrome, also known as AIDS, we predict that, for, at least the next decade, its incidence will continue to increase.

This sentence reads too slowly. You should cut the commas after *warnings*, *governments*, *that*, and *for*.

> Although many warnings from governments have been issued about acquired immunodeficiency syndrome, also known as AIDS, we predict that for at least the next decade, its incidence will continue to increase.

On the other extreme, other engineers and scientists scorn commas. These authors will use commas only in the most desperate cases, and sometimes not even then. The result is that the audience can read the sentences in multiple ways.

> After cooling the exhaust gases continue to expand until the density which was high in the beginning reaches that of freestream.

This sentence needs a comma after "cooling" and a set of commas around the clause "which was high in the beginning."

> After cooling, the exhaust gases continue to expand until the density, which was high in the beginning, reaches that of freestream.

The main challenge with using commas is that many rules exist. Many rules are straightforward, while others lie in gray areas. When the rule for inserting a comma is not black and white, how do you decide whether to use a comma? First, you should realize that the purpose of commas is to eliminate ambiguities. Therefore, when unsure about a comma, think about whether your readers would trip if the comma were not there. Second, develop a consistency in your use of commas. If you punctuate a sentence structure one way in the beginning of a paper, you will make life easier on your audience if you punctuate that structure the same way throughout. Given below are guidelines for handling four common situations that cause confusion for readers.

*Insert a comma after an introductory phrase or clause*. One recommendation is to insert a comma after an introductory phrase or clause. When authors ignore this recommendation, ambiguity often results:

> When feeding a shark often mistakes undesirable food items for something it really desires.

A comma is needed after the word *feeding*:

> When feeding, a shark often mistakes undesirable food items for something it really desires.

Although general writing textbooks often say that a comma after an introductory phrase or clause is optional unless ambiguity would occur, I assert that the complexity of engineering and science makes this comma almost mandatory:

> In the semiconductor β-$Ga_2O_3$ the β refers to the most stable phase at ambient conditions and to the monoclinic crystal structure. Because of the semiconductor‘s high bandgap of around 4.7 eV absorption of light in β-$Ga_2O_3$ does not become significant until deep ultraviolet (about 260 nm).

Inserting a comma after each introductory phrase or clause makes these two sentences much easier to read:

> In the semiconductor β-$Ga_2O_3$, the β refers to the most stable phase at ambient conditions and to the monoclinic crystal structure. Because of the semiconductor‘s high bandgap of around 4.7 eV, absorption of light in β-$Ga_2O_3$ does not become significant until deep ultraviolet (about 260 nm).

Simply put, inserting the comma after an introductory phrase or clause makes the writing more straightforward for the author and the reading much easier for the audience. In addition, inserting a comma after an introductory phrase or clause will not cause a mistake. However, not inserting this comma risks ambiguity.

*Place commas around a parenthetical clause*. If you place a comma before a parenthetical clause that occurs in the middle of a sentence, you must place a comma after that clause. Not doing so trips the reader:

> The new conductor, which will be available next week contains barium and copper.

To complete the parenthetical, a comma is needed after the word *week*:

> The new conductor, which will be available next week, contains barium and copper.

Because scientists and engineers know well the importance of closing sets of parentheses in writing codes for computer programs, this punctuation choice should come naturally. Another way to state this rule would be that a single parenthetical comma should not occur between the subject and the main verb. In other words, if you have one parenthetical comma between the subject and the verb, you must have a second.

*Set off contrasting elements with commas*. One straightforward rule for commas is that you should use commas to set off contrasted elements. These expressions often begin with "but" or "not."

> The shark repellent with 20% copper acetate and 80% nigrosine dye was effective against Atlantic sharks, but ineffective against Pacific sharks.

> Many injuries result from shark bumps, not shark bites.

*Separate items in a series of three items or more*. Another common occasion for using commas occurs in a series of three or more items. The punctuation of a series of items can affect how the audience reads that list [2]. How many commas you insert depends on two factors: (1) whether an ambiguity would exist without a comma, and (2) where the document is published. In the United States, most engineers and scientists would write

…nitrogen, oxygen, and hydrogen and carbon.

…neopentane, perdeuteroneopentane, or neooctane.

In the rest of the world, most engineers and scientists would write these two lists as follows:

… nitrogen, oxygen, and hydrogen and carbon.

… neopentane, perdeuteroneopentane or neooctane.

In other words, while all engineers and scientists would punctuate the first list the same, variation exists in the way that they punctuate the first. Why do most engineers and scientists in the United States insert the last comma in the second list? Although the histories of such conventions are difficult to trace, the likely reason is consistency. As indicated by the first example, the last comma sometimes is needed to prevent ambiguity. By inserting the comma every time, scientific authors in the United States remove any guesswork for both the author and the reader.

**The Colon**. The colon is a valuable piece of punctuation in engineering and science. One important use of colons is to introduce a formal list:

We studied five types of Marsupialia: opossums, bandicoots, koalas, wombats, and kangaroos.

Note that what is on the left side of a colon should stand alone as a sentence. Colons should not break continuing statements.

The five types of Marsupialia studied were: opossums, bandicoots, koalas, wombats, and kangaroos.

In this case, you should remove the colon:

The five types of Marsupialia studied were opossums, bandicoots, koalas, wombats, and kangaroos.

Besides introducing lists, colons are also used for definitions:

The laboratory growth of this germanium crystal made possible a new astronomical tool: a gamma-ray detector with high-energy resolution.

Yet another use for colons is to introduce equations.

The absorptance ($A$) is calculated by the following relation:

$$A = 1 - kR,$$

where $k$ is the correction factor and $R$ is the measured reflectance.

**The Semicolon**. The semicolon, which is a stronger piece of punctuation than a comma, is fussy. Because its purpose is to join elements of a sentence that are parallel in structure, the semicolon is not to be tossed into sentences whenever an author is unsure what punctuation to use. In scientific writing, perhaps the best use of a semicolon is to connect complex items in a list:

Four sites were considered for the research facility: Livermore, California; Albuquerque, New Mexico; Los Alamos, New Mexico; and Amarillo, Texas.

Note that commas could not effectively separate these items, because each item contains a comma. Note also that the semicolons in this sentence appeared after a colon. Without the preceding colon, using the semicolons would unsettle many readers because the wording on the left side of the first semicolon is not truly parallel with the wording on that semicolon's right side:

The four sites considered for the research facility were Livermore, California; Albuquerque, New Mexico; Los Alamos, New Mexico; and Amarillo, Texas.

Another accepted use of the semicolon is to join two independent clauses closely linked in thought:

No cure exists for Alzheimer's disease; it brings dementia and slow death to thousands of Americans every year.

Although the above sentence is fine as written, many professional authors simply would have placed a period after "disease."

**The Dash**. Like the semicolon, the dash is stronger than a comma. Unlike the semicolon, which is fussy, the dash is flexible. The dash, more precisely knows as the ***em-dash***, often acts as a parenthesis. For that reason, dashes can set off parenthetical remarks that commas cannot clearly separate:

> The unique feature of the design is a continuous manifold, which follows a unidirectional—as opposed to serpentine—flow for the working fluid.

Dashes can also set off end phrases and clauses that would be difficult to read if separated by commas:

> After one year, we measured mirror reflectivity at 96%—a high percentage, but not as high as originally expected.

Be careful with the dash. Too many dashes will break the continuity of your writing. Also, note that no space either precedes or follows an em-dash. Finally, note that em-dashes (—) are different from hyphens (-) and ***en-dashes*** (−). In scientific writing, the main use of an en-dash is to show a range: "Temperatures in Death Valley have varied from 15–134°F."

**Quotation Marks**. In the United States, end quotation marks go outside of periods and commas. This rule confuses many engineers and scientists because in Europe and other parts of the world, quotation marks generally appear inside of periods and commas.

| | |
|---|---|
| Europe: | According to Einstein, "God does not play dice". |
| United States: | According to Einstein, "God does not place dice." |

**Hyphens**. Compound words are common in scientific writing. Sometimes you can find the accepted spelling of these compounds in the dictionary. Many times, though, you cannot. In such cases, you have to decide whether to insert a hyphen. In other words, should you write fly ash or fly-ash, flow field or flow-field, or cross section or cross-section? Few timeless rules exist here, because many compounds start out as two words and then acquire hyphens after years of use. Although few clear-cut rules exist, identifying the compound's part of speech (noun or adjective) will help you decide.

The trend in spelling compound nouns is away from the use of hyphens because hyphens make the writing appear more complex. Therefore, you should write compound nouns as

cross section
flow field
fly ash

However, when compounds appear as adjectives in front of nouns, the trend is to use a hyphen to avoid misleading the reader. Therefore, write

cross-sectional measurements
flow-field predictions
fly-ash modeling

**The Slash**. As stated earlier in this book, the slash is an ugly piece of punctuation that adds significant complexity to the language. To reduce this complexity, you should avoid word constructions that incorporate slashes. The best solution is to replace the slashed compound word with just a single word—for example, replace *demonstrate/show* with *show*. When that possibility does not exist, replace the slash itself with a conjunction such as *and* or *or*. In other words, do not write

…he/she…

…s/he…

…experimental/computational techniques…

Instead, write

…he or she… (or revise the sentence to use *they*)

…she or he… (or revise the sentence to use *they*)

…experimental and computational techniques…

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2. Lynne Truss, *Eats Shoots & Leaves: The Zero Tolerance Approach to Punctuation* (New York: Gotham Books, 2003).

# Usage: Avoiding Egregious Errors

*The best of us sometimes get exasperated with the complexities of using English. Believe me, it is worth the effort. Life might be easier if we all spoke Latin. But the quirks, the surprises, the ever-changing nature of English—these are the differences between a living language and a dead one* [1].

—Patricia T. O'Conner

Usage refers to the way that we use words. For example, when is it proper to use *principle* as opposed to *principal?* Likewise, when should you select *criterion* as opposed to *criteria*? Because English contains words from so many different languages, learning all the usage rules of English is challenging. In effect, English has few rules for grammar, but many rules for usage.

As far as the importance of usage for the writer, Stephen Pinker makes a valid point in his statement, "Rules of usage are well worth mastering, but they pale in importance behind principles of clarity, style, coherence, and consideration for the reader" [2]. Still, to avoid distracting your audience from your message and to avoid losing credibility with professional audiences, you should try to learn the most important rules of usage.

Not all usage errors strike audiences the same way. To reflect the severity of an error or the amount of unwanted attention that the error receives, this appendix again applies different colored bullets:

- ● unsettles a significant number of readers
- ● distracts a significant number of readers
- ○ is noticed by only a few readers


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9

For an error such as confusing the verb *affect* for the noun *effect* (●), many scientific readers are unsettled to the point of losing confidence in the author. Given how often these two terms occur in scientific writing, the audience might question how much the author reads. With an error such as confusing *principle* and *principal* (●), a significant number of readers are distracted, but not unsettled. Finally, with an error such as using *due to* when *because of* is appropriate (○), few readers even notice. In addition, most of those who do notice have likely seen the error so often that they might not even mark the error when editing.

Many usage rules, such as the rules governing pronoun references, are intended to avoid ambiguities. Other usage rules, such as using a plural verb with a plural subject, meet readers' expectations. However, some usage rules, such as not using contractions, are more difficult to justify. In school, I was confused in English courses because the rules that instructors would teach in composition classes contradicted the abuses of those rules in literature classes. However, just as different levels of dress depend on the formality of the occasion, so too do different levels of usage rules depend on the formality of the writing. For that reason, even though Mark Twain used contractions throughout *The Adventures of Huckleberry Finn*, engineers and scientists should not use those same contractions in papers or reports.

Many of the usage errors in this appendix I have learned the hard way, by making the mistakes in my writing and then being corrected. Generally, these misuses arose from what I assumed to be proper, but turned out to be otherwise. I grew up in southern Appalachia, an area of the country not known for its adherence to the usage rules of English. Although my childhood home does not excuse my past errors of usage, my experience shows how easy it is to be influenced by the language we hear. Incorrect usage can spread quickly and widely. For instance, how many times have you heard someone say *center around, irregardless, is comprised of,* or *very unique?* Although all of these phrases violate usage rules for proper English, all are widely spoken and, not surprisingly, widely written.

***a, an*** (●) Use *an* for indefinite singular nouns that begin with vowel sounds: an atom, an egret, an intern, an orangutan, an ultraviolet ray, or an hour. Use *a* for indefinite nouns that begin with a consonant sound: a llama, a hysterectomy, or a utility ("y" sound). Notice that as the pronunciation of a word changes over time, the article before it may change as well. For instance, in the 1800s, when the "h" in *historical* was silent, *an* preceded the word. Later, when the "h" became pronounced, *a* preceded it. Notice also that a gray area exists with abbreviations such as *UV.* If your audience reads the abbreviation as "you vee," then use *a.* However, if your audience reads the abbreviation as "ultraviolet," then use *an.* If your audience could read the abbreviation either way, then choose one article (*a* or *an*) and remain consistent.

***adverse, averse*** (●) The word *adverse* means unfavorable, and the word *averse* means in opposition to: "Because of the adverse preliminary results, we were averse to continuing the funding."

***affect, effect*** **(●)** The word *affect* is almost always a verb with the meaning to influence. The word *effect,* on the other hand, is usually a noun and means a result ("greenhouse effect"). A cause for confusion is that *effect* can also be used as a verb meaning to bring about: "She effected the change of orders." Adding even more confusion to the situation is that in the field of psychology, *affect* is used as a noun with the meaning of an "emotional response." Should you have a problem differentiating between these two words, then you should use *affect* solely as a verb meaning to influence and use *effect* solely as a noun meaning a result.

***alot*** **(●)** There is no such word as *alot.* There is, however, the noun phrase *a lot.* Because many consider this phrase to be informal, you should avoid using it in professional documents.

***alright*** (●) There is no such word as *alright.* What should be written in such cases is the phrase *all right.*

***alternate, alternative, option*** (○) Strictly speaking, the noun *option* refers to a choice among three or more things: "To treat this disease, we have three options." In contrast, the noun *alternative* refers to a choice between two things: "To measure temperature in this flow, we have two alternatives." Finally, the noun *alternate* refers not to a choice, but to a substitute: "He is the alternate for the committee." With regard to the adjective *alternate,* it refers to something that occurs in turns, one after the other: "The zebra's coat is marked by alternate stripes of black and white." These distinctions are fading. For instance, almost all publications accept the phrase "several alternatives."

***amount, number*** (●) In general, use *amount* for items that cannot be counted and *number* for items that can. For that reason, write "a large amount of water," "a significant amount of grain," and "a noticeable amount of fish left on the plate." Likewise, write "a number of cells," "a number of errors," and "a number of fish in the stream." An important exception exists: With sums of money, *amount* is used, as in "a large amount of money."

***and/or*** (see "Avoid needless complexity" in Lesson 2)

***anxious, eager*** (●) In formal writing, the word *anxious* means awaiting something with apprehension, while *eager* means awaiting something with enthusiasm. Therefore, if an author were to write, "I am anxious to begin work," the author would suggest that he or she is not looking forward to the job. If the author wants to convey positive expectations, he or she should write, "I am eager to begin work."

***as, like*** (●) In formal writing, the word *like* is strictly a preposition and introduces prepositional phrases: "Like Earth, the planet Mars has an elliptical orbit." The word *as* is a ***subordinate conjunction*** and introduces clauses: "The airfield looks as it did in 1937 when the Hindenburg dirigible exploded." Although this distinction, once strong, is fading, many respected publications such as *The Wall Street Journal* still hold to the rule.

***because* of, *due* to** (○) The phrase *due to* modifies a noun: "The failure was due to the low temperature." The phrase *because of* is for modifying verbs: "The steel failed because of the low temperature." If the phrase follows any verb other than the verb *to be,* use *because of.* Also, if the phrase introduces the sentence, use *because of.*

***bi-*** (○) The prefix *bi-* means twice. However, confusion arises over whether the prefix means that you multiply by two or divide by two. For the most part, *bi-* means that you multiply by two. For instance, *biennial* means once every two years, and *bimonthly* means once every two months. An exception, though, is *biannual,* which means semiannual, or twice a year.

***center around*** (●) The phrase *center around* makes no physical sense. You should write either *center on* or *revolve around.*

***compare to, compare with*** (○) When using criteria to compare items of a certain category, use *compare with:* "In his study, Barnhart compared drug treatments with radiation treatments." When making an analogy to something from a different category of things, use *compare to:* "Freud compared the relationship of the ego and the id to a horse and its rider."

***compose, comprise*** (●) The word *comprise* literally means to include. Most conservative sources such as *Elements of Style*by Strunk and White hold to that literal definition [3]. For that reason, conservative sources insist on the whole comprising the parts, not the reverse. Moreover, conservative sources shun the phrase *is comprised of* because it makes no sense. Although misuse of *comprise* is rampant, many managers and editors are still distracted by the mistake because the popular book *Elements of Style* argues for the strict usage.

***continual, continuous*** (●) The word *continual* means repeatedly: "For two weeks, the sperm whales continually dived to great depths in search of food." The word *continuous* means without interruption: "The spectrum of light is continuous." Given this distinction, the commonly used phrase "make continuous improvements" is an exaggeration unless the people making the improvements do not sleep or break for meals.

**contractions** (●) In formal professional documents, contractions such as *can't, don't,* and *it's* are not accepted. The question is an issue of formality, not correctness. Put another way, using a contraction in a scientific document is akin to showing up to an interview in a t-shirt.

***criterion, criteria*** (●) *Criterion* is the singular form, and *criteria* is the plural form. Note that the Greek origin of this word accounts for the unusual plural form. The same plural form occurs with *phenomenon* (*phenomena*).

***data* as a singular** (○) The word *data* is a plural form of *datum,* a Latin word. Because *datum* is seldom used as the singular form, many sources consider *data* acceptable as either singular or plural. Some conservatives, though, refuse to accept this word as singular. If you need a singular form and do not want to distract your conservative audience, spend an extra word and write *data point.* Doing so circumvents the controversy by using *data* as an adjective.

***different from, different than*** (○) Use the phrase *different from* and you will not be wrong: "This design is much different from the others." As Bernstein points out [4], odd occasions arise in which using *different from* causes cumbersome constructions, such as "different from that which." In these odd cases, substituting "different than" is acceptable. Otherwise, it is not.

***due to*** (see ***because of, due to***)

***effect*** (see ***affect, effect***)

***enormity, enormousness*** (●) Everyone agrees that *enormousness* means "a huge size." Those with a liberal view of language accept that *enormity* also has this definition. In the eyes of conservatives, though, *enormity* has only one meaning: "a monstrous or horrible act." For that reason, in the eyes of conservatives, the engineer who wrote the phrase "the enormity of our solar tower" degraded his own work.

***ensure, insure*** (○) In British English, *ensure* means "to make sure or certain," and *insure* means "to guarantee with insurance against risk or loss of life." American English, on the other hand, allows *insure* to have both meanings. If your audience includes those educated in the United Kingdom, then you should distinguish as well.

***farther, further*** (●) Conservative sources distinguish between *farther* and *further*, advocating that *farther* be used for distance and that *further* be used for all other variables: time, intensity, and so on. However, some conservative sources, including Bernstein [4], admit that *further* will eventually become accepted for all uses.

***fewer, less*** (●) In general, use *fewer* for items that can be counted and *less* for items that cannot. For that reason, write "fewer cells," "fewer errors," and "fewer fish in the stream." Likewise, write "less water," "less air," and "less foliage." Note that you usually treat money and time as continuous quantities: "less than 1 million dollars" and "less than 100 years ago."

**foreign words in italics** (○) When incorporating foreign expressions into English, you should place those words in italics. Note, though, that once an expression has been used long enough, the italics are often dropped, such as with "in vitro" and "in situ." Some expressions appear to be moving from italics to normal type. For instance, "*et al.*" is written in some journals, but "et al." is written in others. In such cases, choose what is in line with your document's format and the audience's expectations. Finally, as discussed in Lesson 2, many foreign abbreviations such as "e.g." add unnecessary complexity to the writing. A simpler style would call for replacing this abbreviation with "such as."

***good, well*** (●) By definition, adjectives such as *good* or *efficient* modify nouns and pronouns. Also, by definition, adverbs such as *well* or *efficiently* modify verbs, adjectives, and other adverbs (granted, the word *well* is sometimes an adjective, but with a different meaning). Given these definitions, you should not use an adjective such as "good" or "efficient" to modify a verb's action:

Incorrect: The design worked so good the first time that we did not bother making changes.

Correct: The design worked so well the first time that we did not bother making changes.

Likewise, do not use the comparative form of an adjective, such as *quicker,* to do a job that a comparative adverb, such as *more quickly*, should do:

Incorrect: This computer chip processes data much quicker than the older chips do.
Correct: This computer chip processes data much more quickly than the older chips do

***he or she*** Some languages have a singular pronoun to refer to an unspecified person regardless of gender. English has the word *one,* but it is seldom used in this way. For that reason, you should be sensitive to the way that you refer to an unspecified person. In such cases, just using the word *he* is unacceptable. So what should you do? To circumvent the problem, an excellent solution is to use the plural form (*they*), which is gender neutral. In cases where the plural is not an option, use either *he or she* or *she or he*. Avoid the ugly *he/she* and the even uglier s/*he* (also see **slash** in Appendix B).

***hopefully,* to mean "it is hoped that"** (○) Just as ***regretfully*** means in a manner full of regret, *hopefully* means in a manner full of hope:

Correct: We looked hopefully to the courts for a ruling on the contract dispute.

In formal writing, using *hopefully* to mean "it is hoped that" will distract some of your readers:

Mistake: Hopefully, the antibodies will destroy the cancer cells.
Correction: It is hoped that the antibodies will destroy the cancer cells.

While English has *hopefully* to be analogous with *regretfully*, English does not have a word that is analogous with *regrettably,* which means "it is regretted that." For that reason, when you want to write "it is hoped that," you should write "it is hoped that."

***I, me*** (○) Use *I* for subjects and use *me* for direct objects, indirect objects, and objects of prepositions. For that reason, write *between you and me,* not *between you and I.* As the title of Patricia O'Conner's *Woe Is I* suggests [5], a common error occurs in which the author chooses *me* instead of *I* for a subject (or ***predicate nominative***). Typically, this error occurs with clauses in which the verbs are understood:

| | |
|---|---|
| Mistake: | She does parallel tasks much more efficiently than me. (*"me" is incorrect*) |
| Correction: | She does parallel tasks much more efficiently than I. (*an understood verb, "do," follows "I"*) |

***if, whether*** (○) Choose *whether* when indicating possibilities: "We must decide whether to use liquid sodium or molten salt." Select *if* when indicating condition: "We will use liquid sodium if we can ensure that it is safe."

***impact,* to mean "effect"** (○) Comets have impacts with planets, speeding cars have impacts with trees, but greenhouse gases have "effects" on global warming. At least, such is the feeling of readers who believe that using *impact* for anything other than a physical collision is imprecise and overstated. Restricting the use of *impact* to physical collisions is not easy, though, because *impact* has lodged itself into several phrases such as "environmental impact statement" with little chance for revision.

***impact,* used as a verb** (●) More disconcerting to many readers than using *impact* as a noun to mean "effect" is using *impact* as a verb to mean "affect." This latter use you should simply avoid.

***irregardless*** (●) The construction *irregardless* is not proper English. Use *regardless.*

***its, it's*** (●) The word *its* is the possessive form of the pronoun *it* and means "of it." The word *it's* is a contraction and means "it is." A few hundred years ago, someone decided on these meanings. Accept them, learn them, and never confuse them.

***lead, led*** (●) The present tense of the verb *to lead* is *lead,* and the past tense is *led*:

| | |
|---|---|
| Present tense: | Strong managers lead by example. |
| Past tense: | Who led last month's meeting? |

Although this rule is straightforward, many people mistakenly write *lead* for the past tense form. Confusing the issue for these wayward writers is that the noun *lead* (Pb) has the same pronunciation as the past tense verb *led*, but is spelled the same as the verb's present tense *lead.*

***lie, lay*** (●) *Lie* means to recline or rest on a surface: "The patient had such a severe rash that he could not *lie* still for more than a few seconds." *Lay* means to place or set down: "Lay the drugged calf carefully on its side." Confusion arises because the past tense of *lie* is *lay:* "Yesterday, the patient lay on his side." Note that the past tense of *lay* is *laid:* "Last night, I laid the form on your chair."

***medium, media*** (○) *Medium* is the singular form, and *media* is the plural form. Note that the Latin origin of this word accounts for the unusual plural form. The same plural ending occurs with *stratum* (*strata*).

**misspellings** (●) Misspellings are different from simple typos. In this book, a misspelling is an incorrect spelling that a spell-checker would catch (writing *undoubtably* as opposed to *undoubtedly*), while a **typo** is an incorrect spelling that a spell-checker would miss (typing *then* rather than *than*). Misspellings often offend the audience more than typos because misspellings suggest that the author did not take the time to pay attention to the word processor's spell-check. In some situations, such as web pages, performing a spell-check is difficult. Unfortunately, you are held to the same standards. The correctly spelled words given below are commonly misspelled in professional writing:

| | |
|---|---|
| accommodate | maneuver |
| acknowledgment | millennium |
| bureaucratic | occurred |
| calendar | perform |
| dependent | receive |
| embarrassment | referred |
| indispensable | separate |
| maintenance | substitute |

***more than, over*** (○) To avoid tripping your readers, reserve the word *over* for physical position ("clouds passed over the solar collector") and for range ("over the past 35 years"). When you are referring to one quantity exceeding another, use *more than* or *greater than:* "The top of the Tower of Pisa leans more than 5 meters off center."

***more important, more importantly*** (○) A common error is to place *more importantly* at the beginning of a sentence to indicate the meaning "what is more important." The correct choice in this case is the adjective phrase *more important*:

More important, the cancer spread to the liver.

The adverbial phrase "more importantly" means something different: "in a more important manner":

In the assessment, the leak was viewed more importantly than it should have been.

***nauseated, nauseous*** (●) The word *nauseated* means to feel sick to one's stomach, while the word *nauseous* means causing one to become sick. For that reason, you should write, "The fumes caused us to become nauseated." Here, the fumes are nauseous, but those who breathe the fumes become nauseated.

***number*** (see ***amount, number***)

**numerals, when to write out** (see Appendix D)

***panacea for*** (○) The word *panacea* means a cure-all. Many people mistakenly misuse this word by saying a "panacea for" a specific class of problems. In such situations, *panacea* is inappropriate. What the writers should use is the word *cure.*

***penultimate*** (●) Often misused, *penultimate* is an adjective meaning next to the last. It is not a fancier way to express the meaning "ultimate."

***phenomenon, phenomena*** (see ***criterion, criteria***)

***plethora,* to mean simply "large number"** (●) Often misused, *plethora* is a noun meaning an excess or overabundance. For that reason, using *plethora* to indicate a large amount ("a plethora of funding opportunities") distracts a significant number of readers. Correct usage requires using *host* in place of *plethora*, or *many* in place of *a plethora of*.

**possessives** (●) For most singular nouns, you form the possessive by adding *'s*: "someone else's decision," "Gauss's Law," and "your boss's authority." Exceptions include a handful of people and places in which the possessive form does not add an *s* sound to the pronunciation (for instance, "Archimedes' principle" and "Mount St. Helens' eruption"). For most plural nouns, you form the possessive by adding an apostrophe: "the wolves' tracks in the snow." Exceptions include irregular plurals ("the children's flu shots").

***principal, principle*** (●) The word *principal* can be either a noun or an adjective. As an adjective, *principal* means main or most important. The word *principle* appears only as a noun and means a law, as in "Archimedes' principle."

***s/he*** (see ***he or she***)

***stratum, strata*** (see ***medium, media***)

**subject–verb disagreement** (●) Each subject must agree in number with the verb. When you have a singular subject, readers expect you to use a singular verb, and when you have a plural subject, readers expect you to use a plural verb.

Example: A series of shocks often precedes a large earthquake. (*singular subject, singular verb*.)
Example: Two aftershocks of the earthquake were almost as powerful as the earthquake itself. (*plural subject, plural verb*.)

In some cases, deciding whether the subject is singular or plural is not straightforward. For instance, compound subjects are sometimes treated as single units:

> Under these conditions, the simultaneous seeding of the fluid's flow and measuring of the fluid's temperature is difficult.

Also, some foreign words such as *criterion* (Greek), *phenomenon* (Greek), and *stratum* (Latin) have unusual plurals: *criteria, phenomena,* and *strata.*

Mistake: The phenomena was studied.
Correction: The phenomena were studied.

Moreover, words such as *none, some, number,* and *all* are singular in some instances, but plural in others.

Example: The number of observations was twenty.
Example: A number of observations were made.

Also challenging is determining the number of a verb following the phrase "one of." In the example below, you would use a singular verb to agree with the subject "one":

Example: In the sinking of the *Titanic,* one of the remaining mysteries is whether the *California* saw the distress flares of the sinking ship. (*singular verb "is"*)

However, in a dependent clause that follows "one of the people who "or" one of the things that," you should choose a plural verb because the *who* refers to the plural noun *people* and the *that* refers to the plural noun *things.*

Example: The manned expedition to Mars is one of those projects that call on scientists and engineers to estimate how much advancement in technology will occur. (*plural verb "call"*)

Finally, if the subject consists of two singular nouns joined by *or, either ... or,* or *neither ... nor,* the subject is singular and requires a singular verb.

Example: Neither oxygen nor nitrogen is a noble gas

If the subject consists of two plural nouns joined by *or, either ... or,* or *neither ... nor,* the subject is plural and requires a plural verb.

Example: Neither ceramics nor gases conduct electricity at low voltages

If the subject consists of a singular noun and a plural noun joined by *or, either ... or,* or *neither ... nor,* the number of the second noun determines whether the verb is singular or plural.

Example: Neither the pilot nor the crew members were present. (*The second noun "crew members" is plural; therefore, the verb is plural.*)

**subjunctive mood** (○) A verb has a mood. For instance, a verb's indicative mood states a fact, and a verb's imperative mood expresses a command. The subjunctive mood occurs in special circumstances, most often to state conditions that are improbable or contrary to fact.

If the space ship *were* to attain a velocity near the speed of light, its mass would change.

If I *were* you, I would apply for the position.

Other examples of the subjunctive mood are in clauses following demands or desires:

The manager demanded that the proposal *be* reviewed.

I wish that I *were* going.

***than, then*** (●) The word *than* is a conjunction that is used for comparisons: "The electrons move more quickly than the ions." The word *then* is an adverb that refers to time: "Then, we measured the current." Often confused, this word pair would be ranked as a major error except that most readers assume that any misuse is an error in typing, not knowledge.

***that, which*** (●) In choosing between *that* and *which,* use *that* for defining clauses (often called necessary clauses because the information is needed to understand the sentence) and *which* for non-defining clauses (often called unnecessary clauses because the information is additional):

We will select the option that has the highest thermal efficiency. *(The clause specifies which option.)*

We will select Option A, which has the highest thermal efficiency. *(The clause adds a fact about the known option.)*

Notice that you separate non-defining *which* clauses from the rest of the sentence with commas. In addition to having non-defining *which* clauses refer to nouns, many authors also have non-defining *which* clauses refer back to the idea of the sentence:

The curve flattened, which shows that the projectile reached a peak velocity.

A situation in which you might choose *which* rather than *that* for a necessary clause is when you have two *that* clauses in the same sentence. In such instances, many writers use *which* for stylistic variation:

They selected the option that had an operating value in a range which posed no danger.

**typo** (●) A typographical error (often called a "typo") is an error such as a missing word or an incorrectly spelled word that spell-checker could not catch (*poll* as opposed to *pill*). Although audiences are generally more forgiving about these errors than they are about errors that a spell-checker could catch, you should work to avoid them, particularly in portions of documents that receive much attention: titles, headings, summaries, and first sentences.

**unclear pronoun reference** (●) Many ambiguities arise because of mistakes with pronouns. According to Fowler's *A Dictionary of Modern English Usage* [6], an important principle for using pronouns is that the reader should not have "even a momentary doubt" as to what the pronoun refers. Many scientists and engineers, unfortunately, ignore this principle. As discussed in Lesson 3, such authors abuse pronouns, particularly the pronouns *it* and *this*.

***unique*, when modified** (●) The word *unique* is an absolute that does not need a modifier. Either something is unique or it is not. For that reason, the phrase "very unique" makes no sense. Another absolute is the word *critical.* Therefore, shun phrases such as "most critical."

**verb tense** (●) In a document, you should maintain the same reference frame for the tenses of verbs. In other words, if in a document, you assume that an event occurred in the past, then that event should remain in the past for the entire document:

> ***Experiment***. The experiment consisted of a Wolfhard-Parker burner in a stainless-steel container. The burner slot for the fuel flow was rectangular and surrounded on all sides by passages for flow of air. Previous experiments had shown that such a geometry provides a nearly two-dimensional flame.

Because the first sentence places the experiment in the past tense, all details in this section occurring during the experiment are in the past tense, and all details occurring before the time of the experiment are in the pluperfect tense (for example, "had shown"). Notice that the last detail ("provides") is in the present tense because the detail is independent of time.

***which*** (see ***that, which***)

***who, whom*** (○) In the old days, you used *who* for the nominative case (usually the subject of a clause), and *whom* for all other cases (usually the direct object of the clause or the object of a preposition within the clause). Examples are as follows with the clauses in italics:

> Kris has to decide *who will receive the promotion.* (subject of clause)
>
> Angie was the one *whom Kris chose.* (direct object: "Kris" is the subject of the clause)
>
> Do not ask *for whom the bell tolls.* (object of preposition: "bell" is the subject of the clause)

So far, so good. However, some sentences are tricky:

> *Whom will you choose*? (direct object: "you" is the subject of the clause)
>
> Angie was the one *who* Kris decided *should receive the promotion.* (subject of clause: "should receive" is the verb of the clause, and "Kris decided" is a separate clause)
>
> I will award this proposal to *whoever has the lowest bid.* (subject of clause: note that preposition "to" is not part of the dependent clause)

In everyday conversation, many choose *who* over *whom* no matter what the situation. Because so many people speak this way, even when *whom* is the correct choice, this word has begun to sound unusual, even erudite, especially when it is the first word in the sentence. In fact, one person running for a senate seat in Wisconsin changed a campaign ad from the correct usage ("Whom will you support?") to the incorrect usage ("Who will you support?") because the correct usage sounded "uppity."

In his column "On Language" for *The New York Times*, William Safire advised that you should use *whom* for the direct object, indirect object, and object of prepositions in a clause, unless *whom* is the first word of the sentence [7]. In that case, use *who.* Note, though, that more conservative publications such as *The Wall Street Journal* still begin sentences with *whom.*

In a sense, our language is evolving much as a species evolves. This evolution of language is not based on survival of the fittest, but survival of the most efficient. Having just the simple word *who* is more efficient than having to choose between the two words *who* and *whom.* Perhaps if *whom* served a purpose in determining the meaning of a sentence, it would survive, but its role in the evolution of language is similar to the role of the appendix in the evolution of the human body—providing little utility, only pain. For that reason, this word's days are numbered. If not for a beautiful line in a poem, this word might already be gone.

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Appendix D

# Format: Dressing Documents for Success

*Printing should be invisible. Type well used is invisible as type. The mental eye focuses through type and not upon it, so that any type which has an excess in design, anything that gets in the way of the mental picture to be conveyed, is bad type* [1].

—Beatrice Warde

When you write a scientific document, the publishing institution or journal usually specifies the format. On occasion, though, you have to select that design. In such cases, you confront a range of decisions from selecting a typeface to deciding upon the amount of white space that surrounds a heading. In making these decisions, you want to choose a format that is easy to read, that is in character with the type of document, and that emphasizes the most important details. Because of the wide selection of typography and layouts, the best strategy is to consult a graphic designer. Most graphic designers have spent years studying different designs and can tailor a format to meet your needs. When you do not have ready access to a graphic designer, you will have to make these decisions. This appendix presents guidelines for achieving a format that functions well and that looks professional.


M. Alley, *The Craft of Scientific Writing*,
https://doi.org/10.1007/978-1-4419-8288-9

## Choose a serif typestyle for the text portion of papers, proposals, and reports

Typography is that part of format that concerns the choice and size of typestyles. A typestyle, often referred to as font, is a shaped set of alphabetic letters. Hundreds of typestyles exist, a few of which appear in Table D-1.

The typestyle of a document says much about the document. For instance, the typestyle Times conveys a sense of professionalism and authority (Times appears in several newspapers). Times belongs to a class of typestyles known as serif, which have projecting short strokes, such as the little feet on a serif "m." Another category of typestyles is sans serif, which do not have these projecting strokes (consider a sans serif "m"). One of the most common sans serif typestyles is Arial.

In making choices for typography, you want to consider the subject matter, occasion, and audience. One typestyle that is appropriate for the window display of a flower boutique may not be appropriate for the text of a report about flower germination. Given below are general guidelines for typography.

**1.** ***Rely on serif fonts for the texts of longer documents***. If you look at most books and journals, you will see that publishers have used serif fonts for the text of the documents. For example,

**Table D-1.** Common typestyles in scientific documents

| Typestyle | Characters | Class | Principal Uses |
|---|---|---|---|
| Book Antiqua | abcdefghijklmnopqrstuvwxyz | serif | reports |
| Garamond | abcdefghijklmnopqrstuvwxyz | serif | articles |
| Times | abcdefghijklmnopqrstuvwxyz | serif | emails, articles |
| Calibri | abcdefghijklmnopqrstuvwxyz | sans serif | headings, call-outs, emails |
| Arial | abcdefghijklmnopqrstuvwxyz | sans serif | headings, call-outs, emails |

many newspapers use a variation of Times, and many textbooks use a typestyle with the word *book* in its name—for example, Book Antiqua. Newspapers, which have several columns, often opt for Times because it is relatively narrow. Textbooks are generally single columned and are better suited for a wider typestyle, such as Book Antiqua.

Why not use sans serif fonts for the text of a document? One reason is that sans serif fonts do not have a connected baseline. Many graphic designers argue that this baseline makes it easier for the eye to remain on a line of text during reading, thereby preserving the continuity of the reading. For documents with short lines, such as a pamphlet, this lack of a defined line does not pose a problem. However, for documents with longer lines, such as a report, the reader benefits from the continuity that a serif typestyle provides.

Another reason to use a serif typestyle is tradition. Almost all professional books and journals have serif fonts as the typefaces of their texts. Moreover, because many publishers use sans serif fonts for the texts of grade-school readers, many people associate text set in sans serif fonts with that level of writing. Note, though, that for documents read on computer screens, such as emails and websites, sans serif typestyles such as Calibri are readily accepted.

**2.** ***Do not use too many typestyles in a document***. Some people mistakenly try to use several typestyles in a document. What occurs is a mess. In a short document, such as an email, one typestyle suffices. In a longer document, you might use a serif typestyle such as Times for the text and a bold sans serif typestyle such as Calibri for the title and headings. This combination works well—the serif typestyle carries a professional look for the text portion, and the bold sans serif typestyle emphasizes the title and headings.

**3.** ***Be conservative with options such as boldface or italics***. Too much boldface will overwhelm a page and intimidate a reader. Italics, another typeface option, is also difficult to read in large blocks. Occasions in which boldface is appropriate would be in headings or subheadings. Likewise, appropriate uses of italics include subheadings, glossary terms, foreign words, and emphasized sentences (such as commands in instructions). Avoid underline, which is considered a poor person's substitute for italics. In the minds of many graphic designers, word processing on computers has made underlining obsolete.

**4.** ***Use a size that is appropriate for the occasion***. Typeface size is measured in points (one point is about 1/72 of an inch). Table D-2 gives occasions when various sizes of typefaces are used. As a general rule, use 12-point type for the text of documents that are single columned and use a smaller size, say 10-points, for the text of documents that have multiple columns.

**5.** ***Avoid typography that adds*** *needless complexity*. Given the inherent complexity of the subject matter in scientific writing, documents are difficult enough to read. For that reason, you should avoid format guidelines that make the typography even

**Table D-2.** General guidelines for different typeface sizes

| Size | Use |
|---|---|
| 28 points | posters, slides |
| 24 points | titles, posters, slides |
| 18 points | titles, headings, slides |
| 14 points | titles, headings |
| 12 points | text, call-outs |
| 11 points | text, call-outs, references |
| 10 points | call-outs, references, footnotes |
| <10 points | footnotes |

more difficult. For instance, avoid abbreviations for words such as "figure" or "reference." The abbreviations do not save that much space, and the additional periods make the document appear more complicated than it needs to be.

Also, avoid setting text other than acronyms in all capital letters. Some authors mistakenly set titles and headings in all capital letters. These authors fail to recognize that readers recognize words not only by the letters in the word, but also by the shape of the letters—for instance, the shapes of ascenders such as *b*, *d*, and *f* and the shapes of descenders such as *g*, *j*, and *p*. Type that is set in all capital letters dramatically slows the reading speed because readers are unable to recognize words by their shapes.

If you feel compelled to use something besides boldface or italics to separate a heading or illustration call-out, then consider using small capitals, rather than ALL CAPITALS. Because type set in small capitals takes up much less space than type in ALL CAPITALS, this type is softer on the eye.

## For the layout, follow the format in a respected book, report, or journal

Layout is the arrangement of the words on the page. Layout includes the number of columns, the spacing between lines, and the widths of margins. In general, you should consult a graphics designer in selecting a document's layout. When a graphic designer is not available, you should mimic the layout of a professional publication that you find attractive and that matches your occasion. Below are general layout suggestions from graphic designers.

**1.** ***Consider subject matter and audience in layout decisions***. For instance, if the document will have several articles that the audience will read at different sittings, consider a multiple-column layout such as in a newspaper. If the subject matter is a single subject that the audience will read methodically, consider a single-column format such as in a textbook. For a much deeper analysis and an excellent example of the layout of columns, see *Trees, Maps, and Theorems* by Jean-luc Doumont [3].

**2.** ***Be generous with white space***. White space is needed for margins, column divisions, headings, and illustrations. As stated in Lesson 8, white space is important because it helps emphasize information. In essence, white space draws readers into the edges of text.

**3.** ***Choose a hierarchy for the headings and subheadings***. Because headings and subheadings show the hierarchy of topics, you should design a format that visually reflects that hierarchy. Two ways to achieve that visual hierarchy are through white space and typography. The greater the white space around a heading, the more emphasis that heading will receive. For that reason, a first-level heading will have more white space around it than a second-level heading. How should you proportion the white space above and below the heading? As with most aspects of format, no definitive answer exists, but a common practice is to insert at least 50 percent more space above a heading as below. With such a proportion, the reader can readily see which block of text belongs with which heading.

A second way to achieve visual hierarchy for headings is typography. For instance, the higher level the heading, the larger the type size. Another way to separate headings is to use typographical features such as boldface [4].

## Challenge the defaults of Microsoft Word, Excel, and PowerPoint

The Microsoft programs Word, Excel, and PowerPoint are powerful. Each provides many options for designing documents, graphs, and slides that can convey a wide spectrum of information to a variety of audiences and occasions.

Unfortunately, many of the defaults of these programs do not serve scientific writing.

Many defaults for Microsoft Word do not serve reports or journal articles, both of which are bread-and-butter documents in engineering and science. For instance, the defaults of this program call for a sans serif typeface. As mentioned in the first section of this appendix, the typeface for the text of a scientific report or article should be serif. Another problem with the defaults of Word concerns the type size (11 points), which is too small for a single-column document (12 points is better). In addition, the defaults of Word insert vertical space between paragraphs, which throws off the spacing hierarchy for headings and subheadings. To preserve the hierarchy of headings, most book and journal publishers do not insert vertical space between paragraphs.

Likewise, the defaults for line graphs in Microsoft Excel are not suited for engineering or science. Apparently designed for vertical bar graphs, which are common in business, the defaults for graphs in Excel do not serve line graphs, which are the main type of graph in engineering and science. To achieve a graph suitable for engineering and science, you will want to challenge several of Excel's defaults.

For instance, one default to challenge in Excel is the title that the program places over the graph—that title is not needed in a report or article given that your graph will have a caption. If you are creating a line graph, you will also want to challenge the default of having only horizontal grid lines. With a line graph, if you have horizontal grid lines, the audience expects you to have vertical grid lines as well. Often a better choice is to have no grid lines, such as in Figure D-1. Yet a third default to challenge is the box border that Excel places around graphs, because such a box in a document adds noise. Finally, you will want to challenge the placement of a key that Excel assigns to all graphs. The ideal is to have labels on the curves themselves. If that is not possible, then position the key in dead space within the graph to allow for a larger graph on the page.

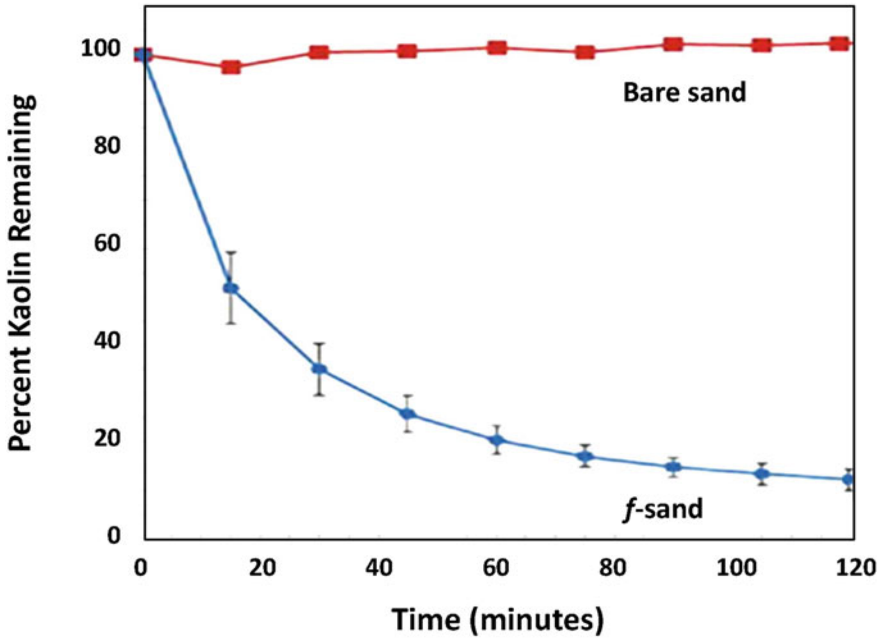


**Figure D-1.** Effective line graph showing the amount of unwanted particles (kaolin) that a special sand, called f-sand, was able to remove from water to purify it for drinking. The f-sand uses crushed moringa seeds [5].

As weak as the defaults are for Microsoft Word and Microsoft Excel, the defaults for Microsoft PowerPoint are much worse. Created in the mid-1980s when incorporating images into computer programs was difficult, PowerPoint's defaults were designed for presentation slides supported primarily by words. Sadly, these defaults have not changed appreciably, even though personal computers can readily incorporate images now and psychology research has found that slides with relevant images are much more effective than slides with only text [6]. To be blunt, PowerPoint's defaults have misled a generation of engineers and scientists into designing slides based on topic-phrase headlines supported by bulleted points. As the fourth chapter of *The Craft of Scientific Presentations* argues, a much more effective approach is to have each slide built on a message (rather than a topic) and to support that message with visual evidence (not a bulleted list) [7].

**alignment** Most formats in professional writing use an alignment in which the text is either aligned on both the right and left margins or aligned on the left, but left ragged on the right. If both your printer and word processing program have proportional spacing, it makes little difference which of these two alignments you choose. Some people prefer the clean and formal look of text aligned on both sides; others prefer the natural look of text left ragged on the right. If either your printer or your word processing program does not have proportional spacing, then you should choose a ragged right margin. Otherwise, your text will have rivers of white space.

**all capital letters** Because text displayed in all capital letters is difficult to read, avoid setting text in all capitals, especially in large blocks, such as what some people do on posters or in emails. When people read words, they do not read every single letter. Rather, to recognize the shapes of many words and syllables, readers rely on the ascenders (*b, d, f, h, k, 1, t*) and the descenders (*g, j, p, q, y*). When you place type in all capital letters, readers lose that recognition and have to read much more slowly.

**bibliography** A bibliography is an alphabetical listing of sources that were consulted in the writing of a document. While a bibliography is less taxing for the author to write, it is not as helpful to the reader looking for sources on specific information. The reason is that a bibliography does not have its ***reference citations*** correspond to specific ***reference listings*** within the text of the document. Therefore, the connections between these sources and the assertions in the text are not clear.

**capital letters in proper nouns** Capitalize the first letter of proper nouns: Avogadro's number, Department of Energy, Bragg angle. Because capital letters add a complexity to the writing, avoid unnecessary capitalizing of terms such as "bremsstrahlung," "x-ray," "mechanical engineering," and "production phase." Note that "x-ray" was originally capitalized, but that complexity fell away once the term became more familiar. Because some capitalizations change with time, a number of capitalizations fall into a gray area. For instance, do you write the "Space Shuttle Discovery" or the "space shuttle *Discovery*"? Both forms appear in the literature. In such cases, choose one form and remain consistent.

**capital letters in titles and headings** Most graphic designers choose initial capital letters for titles and headings. One common convention for initial capitals is to capitalize the first letter of the first and last words—no matter what the words. Then, you capitalize the first letter of every included word except for articles, conjunctions, and prepositions that have fewer than five letters. Examples of words not capitalized are *a*, *an*, *and*, *but*, *for*, *from*, *in*, *into*, *nor*, *on*, *or*, *the*, *to*, *with*, and *yet*. Note that you would capitalize the short word *Is* because it is a verb. Finally, note that for a title or heading that is a sentence, many professional publications capitalize the title or heading with sentence capitals (just the first letter of the first word) for easier reading.

**equations, incorporating into documents** Several formats exist for incorporating equations. This appendix presents one. Center and set apart equations from the text with white space. Using Arabic numerals, number those equations that are referred to in the text. An example would be

$$S = 2\pi\mu r. \tag{1}$$

When referring to equations, call them by their names: equation 1, equation 2, and so on. Also, when incorporating an equation, treat the equation as part of the introducing sentence. An example would be as follows: "The voltage $V$ is given by

$$V = IR, \tag{2}$$

where $I$ is the current and $R$ is the resistance."

**figures, incorporating into documents** Figures include photographs, drawings, diagrams, and graphs. In formal writing, the convention is that each figure should appear below the completed paragraph that introduces that figure. If not enough space is available below the completed paragraph, then the text continues for the rest of that page, and the illustration appears toward the top of the next page. (Note that the graphic designers of journals will break this rule for typeset papers that are formatted with multiple columns.) Also, when placing an illustration into a document, leave more space between the illustration and the text than you leave between the illustration and its caption.

In most formats, captions for figures appear below the figure, as shown in Figure D-2. A figure caption contains a phrase that identifies the figure. In some formats, the caption also contains a sentence or two that explains important details in the figure. When referring to figures, call them by their names. A common convention is Figure 1, Figure 2, Figure A-1, Figure A-2, and so forth. In this convention, Figure A-1 and Figure A-2 would appear in Appendix A.

**headings** Several formats exist for headings, subheadings, and sub-subheadings, one of which is as follows:

| | |
|---|---|
| 1st Level: | 18 points, bold; 3 line skips before, 2 line skips after; left justified |
| 2nd Level: | 14 points, bold; 2 line skips before, 1 line skip after; left justified |
| 3rd Level: | 12 points, bold; 1 line before, 0 line skips after; left justified |

In this format, the typography and placement of the headings distinguish their hierarchy. This system changes somewhat with the document's length. In short reports, the major heading is the report's title, while in longer reports, the major headings serve as the names of the sections or chapters (in the case of dissertations and theses). In these longer reports, the major headings follow one another in a continuous fashion, unless the reports are book length, in which case the major headings begin on new pages.

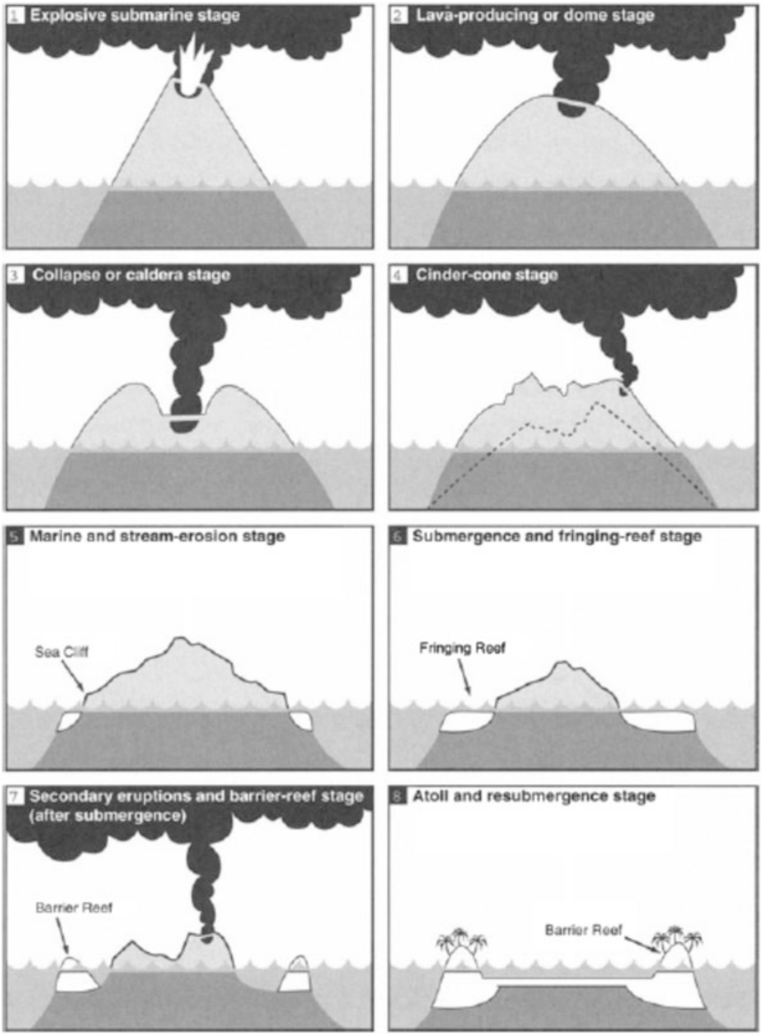


**Figure D-2**. Eight stages of a Hawaiian volcano [8]. The first four stages constitute the building stages, and the remaining four constitute the declining stages

Many company formats call for complex strings of numbers to show the hierarchy of headings (1.0, 1.0.1, 1.0.1.1). While such a system might serve an instruction manual that includes many internal references to other sections, this system is needlessly complex for most reports and does not visually reveal the hierarchy of headings as well as a system based on white space and typography does.

Another consideration for headings occurs when formatting electronic files. In such cases, using a defined format such as Heading 1, Heading 2, and Heading 3 has many advantages. By simply redefining the particular heading format, you can change the format for all the headings of that level in the document. In long documents, this ability to make global changes can save much time.

**indents of paragraphs** Although some formats call for no indents of paragraphs, most formats do, particularly those created by graphic designers. Not indenting paragraphs requires additional vertical space to be inserted between paragraphs. This additional vertical space distorts the hierarchy of headings. In worst-case scenarios, sections have more space between paragraphs within the section than between the heading and the first paragraph. Unfortunately, the World Wide Web is influencing this choice because some browsers do not recognize paragraph indents. One exception to this book's call to indent paragraphs would be the first paragraph of a chapter, section, or glossary listing. For such paragraphs, many graphic designers choose not to have an indent. Another exception would be formats for emails.

**numerals, when to write out** Numerals are actual numerical figures: 0, −1, 2.76, 3000. Because numerals add complexity to the writing, you should use numerals only when necessary. Multiple conventions exist for when to write out numbers. One convention is to write out numbers less than ten. Another, which I prefer, is to write out numbers that can be expressed in one or two words.

| | |
|---|---|
| one | two thousand |
| thirteen | seventy-six |

Several exceptions exist for when to write out numbers. Some of these exceptions, such as illustration numbers (for example, Figure 2), have arisen from format conventions. Other exceptions, such as negative numbers (−1) and decimals (0.3), have arisen from arithmetic conventions. Still other important exceptions have arisen for convenience and clarity:

| | |
|---|---|
| specific measurements | 12 meters/second |
| percentages | 15 percent |
| consistency within a paragraph | …123, 44, and 9. |
| monetary figures | $3450 |
| large numbers | 46 million, $3 million |

Another exception, which is particular to English, is that you should not begin a sentence with a numeral. An improper beginning then would be

> 64.1 milligrams of copper corroded during the tests.

If a numeral is called for, you should restructure the sentence so that the numeral does not appear first:

> During the tests, 64.1 milligrams of copper corroded.

**plurals of abbreviations and numerals** While plurals for words are readily found in the dictionary, plurals of abbreviations and numerals fall into a gray area, appearing with an apostrophe in some publications and without an apostrophe in other publications. I prefer forming these plurals without apostrophes so that no confusion exists between the plural form and the singular possessive form. For that reason, I advocate writing *CPUs* for the plural of *CPU* and *1990s* for the years between 1990 and 1999.

**reference citations** Reference citations appear at the end of a document or section and take several forms. In a numbered system, citations are listed in the order of appearance in the text. In an author–year system, they are listed alphabetically. As for the citation's form, several possibilities exist. A common form in scientific writing is to list the citation as a single sentence. Examples of this form appear in Table D-3.

**reference listings** When incorporating the opinions, data, and illustrations of other sources into your writing, you must give credit to those sources. In scientific writing, that bestowing of credit occurs through reference listings, which allow the reader

**Table D-3.** One convention for reference citations in science

| | |
|---|---|
| **Book** | **Author, *Title in Initial Capitals and Italics,* edition # (City of Publication: Publisher, Date of Publication), pp. #s.** |
| | Einstein, Albert, *Principle of Relativity* (New York: Dover, 1924), pp. 10, 14-21. |
| | *Handbook of Chemistry and Physics,* 50th ed. (New York: Chemical Rubber Company, 1969), p. 236. |
| **Article** | **Author, "Title in Initial Capitals and Quotation Marks," *Journal Name in Italics*, vol. #, no. # (Date), pp. #s.** |
| | Houghton, R. A., and G. M. Woodwell, "Global Climatic Change," *Scientific American,* vol. 260, no. 4 (April 1989), p. 47. |
| | Edwards, M., "Chernobyl—One Year After," *National Geographic,* vol. 171, no. 5 (1987), pp. 632-653. |
| **Newspaper** | **Author (if known), "Title in Initial Capitals and Quotation Marks," *Newspaper Name in Italics* (Date), sec. #, pp. #s.** |
| | "New Liner Titanic Hits an Iceberg; Sinking by the Bow at Midnight," *New York Times* (15 April 1912), p. 1. |
| **Report** | **Author, *Title in Initial Capitals and Italics,* Report # (City of Publication: Publisher (Company or Agency), Date), pp. #s.** |
| | *Report of the Presidential Commission on the Space Shuttle Challenger,* vol. 1 (Washington, D.C: US Government Printing Office, 1986). |
| **Patent** | **Patent Holder, Patent # *in Italics* (Date of Patent).** |
| | Schawlow, Arthur L., and Charles H. Townes, *U.S. Patent No. 2,929,222* (22 March 1960). |
| **Brochure** | **Author, "Title in Initial Capitals and Quotation Marks," type of document (City of Publication: Publisher, Date), pp. #s.** |

(continued)

**Table D-3** (continued)

| | |
|---|---|
| | League of Women Voters, "Nuclear Waste Primer," brochure (New York: Lyons & Burford, 1993). |
| **Interview** | **Speaker's Name, Speaker's Affiliation (City of Interview: Date of Interview), type of interview.** |
| | Ochoa, Ellen, NASA astronaut (Houston: 5 June 1997), telephone interview. |
| **Letter** | **Author, Affiliation (City: Date of Letter), recipient of letter.** |
| | Alley, Clyde D., Plant Manager of Mason-Hanger Pantex Plant (Amarillo, TX: 3 March 1989), letter to *Amarillo Globe News.* |
| **Website** | **Author, "Title,"** ***web address in italics*** **(City: Sponsor, Date).** |
| | Gannon, Robert, "What Really Sank the Titanic," *http://www.popsci.com/context/features/titanic/* (Norwalk, CT: *Popular Science,* 1995). |
| | "X-34 Model Makes First Captive Test Flight," http://*www.nasa.gov/* (Washington: NASA, 29 June 1999). |

to locate the respective reference citations at the end of the document. In scientific writing, multiple conventions exist for reference listings. Two common examples are a numbered system and an author-year system. The advantage of a numbered system, which this book has used throughout, is a savings in space. An author–year system, on the other hand, establishes from whom the information arose and how current the information is. In such a system, this information is usually placed within brackets in one of the following two ways:

> At Sandia, a chemical process was developed for eliminating nitrogen oxide emissions from diesel engines [Perry and Siebers, 1986].

> At Sandia, Perry and Siebers [1986] developed a new chemical process for eliminating nitrogen oxide emissions from diesel engines.

In this author–year system, for three or more authors, the common convention is to list the first author's name as follows: [Lee and others, 1972] or [Lee et al., 1972]. If the document has no listed author, the convention is to give the first word (not articles, conjunctions, or prepositions) of the document's title: [*Report,* 1986] or ["X-34," 1999]. The full reference citations then will appear in an alphabetical list at the end of your document.

Note that because a numbered system is less intrusive, you may select it when the audience does not require the names and dates of the sources at the moment of reading. Ironically, an author–page number, which most high schools devote much time to teach, is seldom, if ever, used in engineering and science. Named the MLA (Modern Language Association) style, this system serves documents that focus on longer sources—say a comparison of characters in Hemingway's *A Farewell to Arms* and Ondaatje's *The English Patient.*

**tables** Tables are row-and-column arrangements of numbers or words. Unlike captions for figures, headings for tables generally appear above the tables (typically, they are single phrases). For an example, see Table D-4. In the text, call tables by their names: Table 1, Table 2, and so on. Another common table format has the heading centered above the table.

**Table D-4.** Physical characteristics of the planets [9]

| Planet | Diameter (km) | Gravity (earth ratio) | Year (earth days) |
|---|---|---|---|
| Mercury | 5,100 | 0.40 | 87.97 |
| Venus | 12,600 | 0.90 | 224.70 |
| Earth | 12,800 | 1.00 | 365.26 |
| Mars | 6,900 | 0.40 | 686.98 |
| Jupiter | 143,600 | 2.70 | 4,332.59 |
| Saturn | 120,600 | 1.20 | 10,759.20 |
| Uranus | 53,400 | 1.00 | 30,685.93 |
| Neptune | 49,700 | 1.00 | 60,187.64 |

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8. Fred M. Bullard, *Volcanoes of the Earth*, 2nd ed. (Austin: University of Texas Press, 1976).
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# Glossary

Serious analysis of writing, including scientific writing, requires the use of writing terms such as *noun, active voice*, and *infinitive phrase*. While you need not have academic definitions of these terms, you should possess working definitions. One reason is that with such an understanding, you are in a position to better analyze your own writing. A second reason is that you will be much more effective commenting on the writing of others. This glossary provides working definitions not only of writing terms, but also of several publishing terms, such as ***folio*** and ***kerning***, that you might run across in your correspondence with editors.

**active voice** a verb form in which the subject performs the action in the sentence: "The four male elephants abruptly *stepped* away from the water hole and *froze* in unison."

**adjective** a word that modifies a noun or pronoun: "Scientists were surprised when the *huge* earthquake and *unexpected* landslide triggered such a *massive* eruption."

**adverb** a word that modifies a verb, adjective, or another adverb: "When Mount Pelée erupted, the lava gushed *so rapidly* through Saint-Pierre that *only* two citizens survived."

**appendix** a section of a formal report that occurs at end, after the conclusions, so as not to dilute emphasis on the main story of the report. An appendix might consist of secondary information for the report's primary audience or primary information for one of the report's secondary audiences.



M. Alley, *The Craft of Scientific Writing*,
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**appositive** a noun or noun phrase placed next to a noun to define or explain that noun: "*A condition resembling intoxication,* nitrogen narcosis affects divers at depths of 30 meters or more."

**assertion–evidence** an argumentation strategy in which the author backs up each claim (assertion) with evidence. When used in presentations, the assertion–evidence strategy calls for the evidence to be visual: photographs, drawings, diagrams, graphs, films, or equations.

**back matter** the sections of a report following the main text. Examples are the appendices and the glossary.

**call-out** a label that identifies a portion of an illustration

**cliché** a descriptive phrase that has become trite. Common examples are "come up to speed," "sticks out like a sore thumb," and "greatest thing since slice bread." To maintain a professional tone in your scientific writing, avoid such phrases.

**clause** a group of words containing a subject and verb. A clause may be dependent, meaning that it cannot stand alone as a sentence ("when elephants search for food") or independent, meaning that it can stand alone as a sentence ("elephants communicate to one another by making rumbling noises similar to gargling").

**condensed type** type that is thin in proportion to its height

**complex sentence structure** an independent clause joined with one or more dependent clauses. An example would be as follows: "When an elephant wants to communicate with others far away, it often stamps one of its feet." In this example, the words before the comma constitute the dependent clause, and the words after the comma make up the independent clause.

**compound sentence structure** two or more independent clauses joined with a conjunction. An example would be as follows: "An elephant's trunk can strip leaves from thick branches, but it also can perform gentle tasks such as wiping an eye." In this example, the conjunction *but* joins the two independent clauses.

**conjunction** a word that joins words, phrases, or clauses. This book has simplified this term to refer to the following five words: *and, but, nor, or,* and *yet*. In reality, three types of conjunctions exist: coordinating, correlative, and subordinating. Coordinating conjunctions *(and, but, nor, or,* and *yet)* join words, phrases, and clauses of equal rank. Generally, these are the words that people mean when they say the word "conjunction." Correlative conjunctions are coordinating conjunctions used in pairs (*both … and, not only … but (also), either … or,* and *neither… nor*) to join words, phrases, and clauses of equal rank. Subordinating conjunctions are words such as *because, although,* and *when* that introduce dependent (or subordinating) clauses.

**connotation** the implied or associated meaning of a word

**content** the message that the author intends to communicate

**correlating conjunction** (see **conjunction**)

**crop** to cut away parts of an illustration, often a photograph, either to fit into a desired space or to remove unwanted detail

**denotation** the dictionary meaning of a word

**dependent clause** a clause that cannot stand alone as a sentence. Dependent clauses, often called subordinating clauses, begin with subordinating conjunctions such as "although," "when," "because," and "if": "*Because anemometers are* so *delicate,* they cannot be used to measure directly the wind speeds of tornadoes."

**direct object (see object)**

**doublet** an unwanted word occurring twice in succession when only one occurrence was intended ("The vaccine combated *the the* virus").

**em-space** the amount of space taken up by the letter *m*. The length of an em-dash (—) would be the length of the letter *m*. For a discussion of em-dashes, see Appendix B.

**en-space** the amount of space taken up by the letter *n*. The length of an en-dash (–) would be the length of the letter *n*. For a discussion of en-dashes, see Appendix B.

**folio** page number

**form** the format, grammar, punctuation, spelling, and usage of the writing

**format** the way in which an author arranges the type on a page. Format includes such things as the choice of typeface, the spacing between sections, and the referencing system for sources. In professional writing, no single ordained format exists. Although many scientific institutions make similar choices for typography and layout, institutions often strive to vary formatting enough to achieve a distinctive look.

**fragment** a group of words that does not form a complete sentence because either the group of words is missing a subject or verb, or the group of words does not give a complete thought. In the text of a scientific document, sentence fragments severely undercut an author's credibility.

**front matter** the sections of a report (or book) that precede the main text. Examples of possible sections in the front matter are the title page, foreword, acknowledgments, table of contents, nomenclature, and executive summary.

**gerund** a present participle that functions as a noun: "*Walking* is great exercise." Often, the gerund is part of a phrase (called a gerundial phrase) that serves as a noun: "In scuba diving, *ascending too quickly* will not allow your body enough time to dispose of the nitrogen that it has absorbed."

**gerundial phrase (see gerund)**

**grammar** the rules of writing that dictate how words are to be arranged into meaningful sentences. In comparison with other languages such as German, English does not have many rules for grammar. However, English does have a host of rules for usage.

**Gunning Fog Index ($F_i$)** a measure for the complexity index of a piece of writing: $F_i = 0.4\left(\frac{N_w}{N_s} + P_{lw}(100)\right)$, where $N_w$ is the number of words in random paragraph, $N_s$ is the number of sentences in the paragraph, and $P_{lw}$ is the percentage of long words (three or more syllables) in the paragraph. In counting the number of long words, the Gunning Fog Index calls for not counting the following: the first word of a sentence; proper nouns (*California*); or verbs that acquire third syllable on endings *–ed* or *–ing* (for example, *attempted*). For scientific writing, a good score would be between 10 and 13. Such a score would mean that you are choosing words and sentences of an appropriate length for an adult audience, but not so long that the audience focuses too much attention on your style, rather than your content. For reference, *USA Today* has an index of 10, *The Wall Street Journal* has an index of 11, and *Scientific American* has an index of 12.

**illustration** the meshing of words and images in a document. Illustration includes not only the figures and tables themselves, but also the wording that connects those figures and tables to the text.

**imperative mood** a command form of a verb in which the subject is an understood "you." An example is "*Turn* on the computer." The subject of this sentence is "you," even though the word "you" is not explicitly in the sentence.

**indirect object** a noun or pronoun that identifies who or what receives the action of the clause: "NSF awarded *our lab* the contract."

**infinitive phrase** a verb phrase in which the verb is coupled with the word *to*: "*To calculate the energy of the photon,* you multiply its frequency by Planck's constant."

**introductory series** a list of nouns at the beginning of a sentence that defines the subject of the sentence. The introductory series is separated from the rest of the sentence by an em-dash: "*Nitrogen narcosis,* *decompression sickness, and arterial gas embolism*—these are the greatest dangers facing scuba divers."

**jargon** a word, abbreviation, or slang term that is particular to a company, laboratory, or group. Within the company, laboratory, or group, the expressions can be an efficient shorthand for communicating information. However, for outside readers, jargon can alienate.

**justification** alignment of the lines relative to the margins. Left justification means that the text lines up straight on the left margin, while right justification means that the text lines up straight on the right margin. Fully justified text means that the text aligns itself straight on both margins.

**kerning** the degree of overlap among characters of type along the same line.

**language** the way that we use words in writing and speaking. More than just word choice, language also encompasses the order of words, the lengths of sentences, and the connections between sentences.

**leading** the amount of space between lines of type.

**limitations** content that the audience might assume would be covered in a document, but is not. This term often accompanies the term *scope*.

**main text** the sections of a report from the "Introduction" through the "Conclusions." In general, the main text should stand alone as a document written to the primary audience of the report.

**mechanics** grammar, punctuation, spelling, and usage

**noun** a word that identifies an action, person, place, quality, or thing. Examples include "flight," "scientist," "laboratory," "curiosity," and "oscilloscope."

**object** a noun, pronoun, or noun phrase that receives the action of the verb: "The puff adder bit *his ankle*."

**orphan** a single word, from the end of a sentence, title, or heading, appearing on a line by itself. In the layout of a document, you should avoid orphans.

**participle** a special form of a verb. Present participles end in "-ing" (*working*) and past participles often end in "-ed" (*worked*). Participles and participial phrases often serve as modifiers: "*Hunting at night*, the *tagged* tiger was rarely seen *making a kill*." When a present participle serves as a noun ("*Swimming* burns many calories"), the participle is called a gerund.

**passive voice** a verb form in which the subject does not act, but is acted upon: "The wildebeest calf *was attacked* by painted dogs." Note that the document from which this example arises concerns wildebeests, not painted dogs.

**phrase** a group of words that may contain a subject or verb, but not both. Examples include prepositional phrases ("across grasslands"), participial phrases ("foraging for food"), and infinitive phrases ("to warn others in the herd").

**pica** a unit of measurement equal to 12 points, or roughly 1/6 of an inch

**point** a unit of measure for the size of type (1 point $\approx$ 1/72 of an inch). The text of most single-column documents is set in 12-point type.

**predicate nominative** a noun, pronoun, or noun phrase that follows the verb "*to* be" and renames or identifies the subject: "The identified star was actually *a cluster of stars*."

**preposition** a part of speech that indicates a relationship such as time, manner, or place between its object and another word in the sentence. Examples include *about, above across, after, against, beside, between, beyond, by, despite, down, in, inside, like, near, of, through, to, until, upon* and *with.* Prepositions introduce noun phrases that bring these details of time, manner, and place into sentences: "*in* a few hours," "*with* much speed," and "*under* the bridge."

**pronoun** a part of speech that may be used instead of a noun. Examples are *I, he, she, it, you, we,* and *they*.

**punctuation** the rules of writing governing the use of the period, question mark, exclamation point, colon, semicolon, comma, dash, apostrophe, ellipsis marks, slash, and quotation marks

**recto** referring to an odd-numbered page in a document

**reference citation** text block of information at the end of a document that allows the readers to find a specific reference source

**reference listing** number or short text phrase such as [author, year] within the text of document that allows the reader to locate a reference citation at the document's end

**river** distracting spacing within paragraphs (usually between words) that sometimes occurs when type is set fully justified

**roman** referring to normal typeface (as opposed to italics or boldface)

**sans serif** a typestyle, such as Calibri, in which no short strokes stem from the upper and lower ends of letters. Sans serif fonts are often used in posters, presentation slides, and illustrations.

**scope** the boundaries of a document's content. Scope defines what the document will cover.

**sentence** a group of words with a subject and verb that expresses a complete thought. A sentence often contains an object that receives the action of the verb: "The virus attacked the cell." Here, *virus* is the subject, *attacked* is the verb, and *cell* is the object. To this sentence, you could add adjectives, adverbs, phrases, and dependent clauses. While a subject and verb exist in every sentence, an object does not.

**series comma** the comma that appears before the conjunction preceding the last term in a series of three or more items. As an example, consider the series "oxygen, hydrogen, and carbon." In this example, the series comma, often called the serial comma, is the comma after *hydrogen.* Some types of writing such as journalism avoid the series comma unless an ambiguity would exist otherwise. Also see the discussion of commas in Appendix B.

**serif** a type style, such as Times New Roman in which short strokes stem from the upper and lower ends of letters

**simple sentence structure** a single independent clause without any dependent clauses: "Elephants possess a keen sensitivity to ground waves."

**split infinitive** the placement of a word or words between the word *to* and the verb of an infinitive phrase—for example, "to slowly raise" as opposed to "to raise slowly." Also see the discussion of split infinitives in Appendix A.

**structure** the strategy of your writing. Structure includes the organization, depth, and emphasis of details in a document.

**style** (1) the way that you present the document's content, including the way you organize details, the words you select, and the illustrations you choose; (2) those aspects of writing—particularly language, format, punctuation, and usage—that are not universal (this definition would apply in the phrase "style manual").

**subject (of sentence)** who or what the sentence or clause is about. The subject usually consists of a noun or pronoun and its complements ("*Some fuel* is usually left unburned in the tank"). However, a subject can also be a phrase ("Unfortunately, *estimating the exact amount of fuel left in the tank* is difficult") or even a clause ("*What fuel was left in the tank* must have caused the explosion").

**subordinate conjunction** words such as *because, although,* and *if* that introduce dependent (or subordinating) clauses. Because such a clause is dependent, it cannot stand alone as a sentence. Rather, the author should couple the dependent clause with an independent clause to form a complete sentence.

**syntax** the ordering of words within a sentence

**tone** whatever in the writing indicates the attitude of the writer toward the subject

**usage** the rules of writing that govern the proper use of words—for example, the rules on whether to use *affect* or *effect* in a sentence

**verb** a word that indicates an action or a state of being within a sentence: "The shock *shattered* the volcano's summit and *was* responsible for the collapse of the mountain's north side." Finite verbs are capable of making assertions ("fuel *burns*"), while nonfinite verbs (such as participles and infinitives) are not ("fuel *burning*" or "fuel *to burn*")

**verso** referring to an even-numbered page in a document

**warrant** background information that allows readers to appreciate the significance of an assertion

**widow** a single line, from the end of a paragraph, appearing at the top of a printed page or column. In the layout of a document, you should avoid widows

# Index




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