From Research to Manuscript

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A Guide to Scientific Writing

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Contents

Introduction

Observations *Plus* Recipes

It has been said that science is the orderly collection of facts about the natural world. Scientists, however, are wary of using the word ‘fact.’ ‘Fact’ has the feeling of absoluteness and universality, whereas scientific observations are neither absolute nor universal.

For example, ‘children have 20 deciduous [baby] teeth’ is an observation about the real world, but scientists would not call it a fact. Some children have fewer deciduous teeth, and some have more. Even those children who have exactly 20 deciduous teeth use the full set during only a part of their childhood. When they are babies and toddlers, children have less than 20 visible teeth, and as they grow older, children begin to loose their deciduous teeth, which are then replaced by permanent teeth.

‘Children have 20 deciduous [baby] teeth’ is not even a complete scientific statement. For one thing, the statement ‘children have 20 deciduous teeth’ does not tell us what we mean by ‘teeth.’ When we say “teeth,” do we mean only those that can seen be with the unaided eye, or do we also include the hidden, unerupted teeth?

An observation such as ‘children have 20 deciduous teeth’ is not a fact, and, by itself, it is not acceptable as a scientific statement until its terms are explained: scientifically, ‘children have 20 deciduous teeth’ must be accompanied by definitions and qualifiers. The standard way to put science into a statement is to define the statement’s meaning operationally. Instead of attempting a purely verbal definition of ‘teeth,’ for instance, scientists define it by the procedure—the recipe—that has been used when making the observations about teeth.

In science, ‘children have 20 deciduous teeth’ is neither universal nor abstract. It is a record of the result of following a specific recipe, and the statement is scientific only when we include the recipe that was used. For ‘children have 20 deciduous teeth,’ one appropriate recipe would be: “I looked in the mouths of 25 five-year-old boys and 25 five-year-old girls in the Garden Day Nursery School in Cleveland, OH, on Monday, May 24, 2008, and I found that 23 of the boys and 25 of the girls had 20 visible teeth.”

A meaningful scientific statement includes an observation and its recipe, and the standard form for recording meaningful scientific statements is the scientific research paper.

Writing a Scientific Research Paper

Science is the orderly collection of scientific records—i.e., observations about the natural world made via well-defined procedures—and scientific records are archived in a standardized form, the scientific research paper. A research project has not contributed to science until its results have been reported in a standard paper, the observations in which are accompanied by complete recipes. Therefore, to be a contributing scientist, you must write scientific papers.

This book contains my advice and thoughts about writing a scientific research paper. My basic hard-won realization is that writing a good scientific paper takes time. On the other hand, I have found that the writing will seem endless if you begin with the title and slog straight through to the last reference. This approach is difficult, wearing, and inefficient. There is a much more effective way to write.

I suggest that you write your paper from the inside out. Begin with the all-important recipes, the *Materials and Methods*. Next, collect your data and draft the *Results*. As your experiments end, formulate the outlines of a *Discussion*. Then write a working *Conclusion*. Now, go back and write the historical context, the *Introduction*. Only after all else has been written and tidied up, will you have sufficient perspective to write the *Title* and the *Abstract*.

Throughout the writing, your tools and techniques will be the same. You should use precise words and, whenever possible, numbers. You should write direct sentences that follow a straight line from point A to point B. In addition, you should fill all sections of the stereotyped skeleton of a standard scientific paper.

Writing a paper should be an active part of your research. If you wait until your studies are finished before you begin to write, you will miss a powerful tool. Research is iterative—you do, you assess, and you redo, and writing a paper is a way for you to continually make the reassessments necessary for critical and perceptive research.

Your manuscript can even be a blueprint for your experiments. The empty skeleton of a scientific paper poses a set of research questions, and, as you fill in the skeleton, you automatically carry out an orderly analysis of your data and observations. Moreover, by setting new data into the draft of your paper, you can maintain perspective. You will filter out the shine of newness, as your results—even unusual results—are put into the context of your existing data and your full research plan.

As a scientist, you must write, and, as an experimentalist, writing while you work strengthens your research. Writing a paper can be an integral part of observational science.

Scientific Papers Used as Examples

In the text of this book, I rebuild and improve a paper that I wrote in 1985, entitled "Intensifier for Bodian Staining of Tissue Sections and Cell Cultures." I use this paper because it is brief, simple, and well known to me.

Just as a picture is worth a thousand words, an actual example of a well-written scientific paragraph is worth a dozen descriptions of one. To illustrate the craft of scientific writing, I have included excerpts from scientific papers far better than my own.

The excerpts are from articles across the range of scientific studies. For the most part, these papers are lean, logical, and cleanly written. They are examples of good science writing and they have been recommended to me by the editors of the journals in which they appeared. In the text, I refer to the papers by author(s) and date. Here are the full bibliographic citations:

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Part I
TOOLS AND TECHNIQUES

Chapter 1

THE STANDARDS OF A SCIENTIFIC PAPER

1. A STEREOTYPED FORMAT

Research papers are the repositories of scientific observations plus the recipes used to make those observations.

Scientific papers have a stereotyped format:

- *Abstract*
- *Introduction*
- *Materials and Methods*
- *Results*
- *Discussion*
- *Conclusion*
- *References*

The exact section headings sometimes vary, but most scientific papers look pretty much the same from the outside. There are no novel constructions or inventive twists of the narrative. Instead, the framework is unchanging so that the content can be studied without distraction. The predictable form of a scientific paper, with its standard set of sections arranged in a stereotyped order, ensures that a reader knows what to expect and where to find specific types of information.

2. PRECISE LANGUAGE

Within this stereotyped format, the language of a scientific paper aims to be clean, clear, and unemotional.

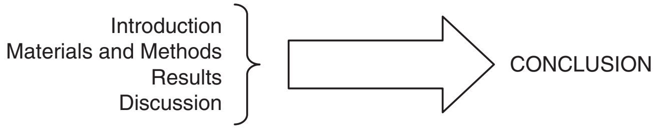
Much of the color of our everyday language derives from ill-defined, emotionally charged, ear-tickling images conjured up by sensuous words such as 'slovenly,' 'sibilant,' and 'sneaky.' Science, however, avoids colorful words.

The essential characteristic of scientific writing is clarity. Slippery words and vague phrases are confusing, and there is no place for ambiguity, arcane language, or froth in the archives of scientific records. In science, descriptions must be precise, recipes must be complete, data must be exact, logic must be transparent, and conclusions must be cleanly stated.

M.J. Katz, *From Research to Manuscript,*

3. A SINGLE, CLEAR DIRECTION

Beyond a stereotyped format and transparent language, a scientific paper also needs clarity of direction. Your entire paper should point inexorably toward its *Conclusion*.



Therefore, as you write, point the way for your reader, and remove tangents and digressions. Keep a single theme at the fore. For example, if your *Conclusion* is about temperature, then temperature should be ever-present in your paper. 'Temperature' should be in the *Title*. The *Introduction* should tell how your predecessors wrote about temperature. The *Materials and Methods* section should detail the instruments that you used and the operations that you performed involving temperature. The *Results* section should include data about temperature, and the *Discussion* section should connect your data to the existing scientific literature about temperature.

4. REVIEWED AND MADE AVAILABLE TO OTHERS

Finally, a scientific paper should be accessible to others. Scientific journals are the traditional mechanisms for reviewing, disseminating, and preserving scientific papers, so submit your paper to a peer-reviewed journal. Having your paper reviewed by experts ensures that it can be understood and used by a broad scientific community. Then, having your paper preserved in a public forum ensures that the scientific community will have the opportunity to use it.

Chapter 2

SCIENTIFIC WORDS, SENTENCES, AND PARAGRAPHS

1. SCIENTIFIC TEXT NEEDS EXACTNESS AND CLARITY

1.1. Write with Precision

In science, your goal is to write a paper that is easy to understand. The art of scientific writing is not in the subtle underlying message conveyed by your prose. Instead, scientific prose is judged by how well it defines the details of the observations that you have made. In a short story, the reader might marvel at the "sensual writing, with hints of the mysteries of space and time." In a scientific paper, however, your prose style should disappear, and the reader should marvel at the realistic, explicit, and cleanly etched picture that you have painted.

Scientific papers have a stereotyped format so that there are no distractions from their contents. Likewise, scientific prose should be formulaic and plain. Here, the medium is not the message, the message is the message. Therefore, when you write a research paper, make your message precise and keep the medium unobtrusive.

To write precisely is to write without adornment. It can be an effort to recognize fluff and imprecision in your own writing, so train yourself to catch and to remove vagaries, emotion, indirectness, and redundancy. (For examples of the simplification of wordy phrases, see **Appendix B** below.)

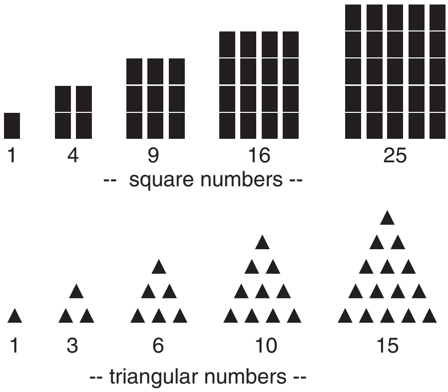
It helps to remember that your goal is to speak plainly, i.e., to write clean straightforward sentences without hedging. Say what you mean directly. For example:

- "It may therefore not be unexpected that …" should be "These results suggest …"
- "An effort was made to …" should be "We tried to …"
- "The sorbitol probably acts to increase …" should be "The sorbitol probably increases …"
- "This gene is of significant interest for understanding commonalities in the evolutionary history of the microorganisms A and B" is clearer, simpler, and more informative when you tell exactly what you have in mind, such as "A single mutation in this gene of microorganism A has brought about its new use in microorganism B"

- "It is our considered opinion that other authorities may have misstated the relative import of such particulate concatenations in the soluble phase of the paradigm" should be written with specifics, such as "In their 1994 paper, Drs. Williams and Wilkins say that the drug's failures are due entirely to the clumping of suspended drug particles. In contrast, we propose that the viscosity of the solvent causes 40–50% of the failures."

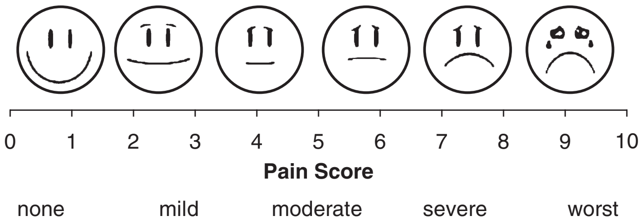
1.1.1. Use Numbers

Numbers have just the right properties for scientific writing: numbers are precise, objective, unambiguous, and without emotional undertones. Moreover, numbers can be used to describe many things in the real world; for example, in a variety of ways, numbers can represent shapes and sizes:



Because quantifiable adjectives are ideal descriptors in science, try to redefine all your adjectives as numbers. 'Tall' should be defined numerically, for example, 'greater than 2 m' or 'greater than 7 km.' Likewise, 'heavy' should be 'greater than 10 kg' or 'greater than 100 kg' or, perhaps, 'greater than 10^5 kg.' If you use 'brief,' tell us whether it means less than a minute, less than a second, or less than a millisecond.

Even the inherently subjective adjective 'painful' should be set as a number on a scale quantifying *how* painful, as is done in most hospitals:



1.1.2. Use Objective Words

Of course, you cannot write with numbers alone. When quantifiable words are not available, you should use as precise and objective a vocabulary as possible.

Whether any particular sentence is precise and objective, depends on the reader's ability to define all its components. For example, "The needle vibrated continuously" is appropriate in a scientific paper if the reader is told which needle, what type of vibration, and over what time period it vibrated continuously. In science, the rule is, *define all your words*.

Beyond this rule, a few writing habits will help to ensure good scientific text. One of these habits is to weed out or replace vague and subjective terms; for instance, remove:

- Expressions with no clear limits, such as
  - a lot, fairly, long term, quite, really, short term, slightly, somewhat, sort of, very
- Words of personal judgment, such as
  - assuredly, beautiful, certainly, disappointing, disturbing, exquisite, fortuitous, hopefully, inconvenient, intriguing, luckily, miraculously, nice, obviously, of course, regrettable, remarkable, sadly, surely, unfortunately
- Words that are only fillers, such as
  - alright, basically, in a sense, indeed, in effect, in fact, in terms of, it goes without saying, one of the things, with regard to
- Casual colorful catchwords and phrases, such as
  - agree to disagree, bottom line, brute force, cutting edge, easier said than done, fell through the cracks, few and far between, food for thought, leaps and bounds, no nonsense, okay, quibble, seat of the pants, sketchy, snafu, tad, tidbit, tip of the iceberg

1.2. Scientific Use of Tenses

Good scientific prose uses a precise vocabulary. Scientific prose also uses verb tenses in a standardized way. When discussing research, the present tense indicates general knowledge and general principles, while the past tense indicates results of experiments.

1.2.1. Present Tense Is for Generalities

Use the present tense for general knowledge statements, widely accepted statements, and statements for which you could cite textbook references; for example:

- "Black-eyed Susan (*Rudbeckia hirta*), a member of the Aster family, is a plant native to North America."
- "Hexoses formed by digestion in the intestinal tract are absorbed through the gut wall and reach the various tissues through the blood circulation."

- "The term 'nuclide' indicates a species of atom having a specified number of protons and neutrons in its nucleus."
- "On a protein-rich diet, the amount of methylhistidine in the urine increases."

1.2.2. Past Tense Is for Specific Observations

Your results—the particular observations that you made during a research study—are bits of history, so use the past tense when you report your experimental results. For example:

- "In photographs of Guatemalan tarantulas, we found that the number of dorsal stripes ranged from six to nine."
- "During his war-time expedition to Guatemala, Rawski (1943) reported finding tarantulas with 9 stripes."
- "Eighteen percent of the patients in our study developed a mild rash."
- "The diodes were compared at regular time points during the next 75 h."

2. THE PARAGRAPH IS THE UNIT OF EXPOSITION

2.1. Each Paragraph Makes One Point

In a research paper, each paragraph should contain one main idea, and the space between paragraphs should be like taking a mental breath. Picture the text as, *Idea #1,* breathe, *Idea #2,* breathe, …

Most people absorb ideas in small chunks, and scientific paragraphs are those small absorbable chunks. You can assess the absorbability of a paragraph simply by counting its sentences. The ideal size for a paragraph is 3–4 sentences, and five sentences are about the upper limit. If you find that you have written six or more sentences without allowing for a mental breath, then go back and break your writing into smaller chunks.

Consider this paragraph about insulin.

- 'To keep all the cells in the body coordinated and working toward the same metabolic goals, the body uses hormones. Hormones are chemicals that are carried throughout the bloodstream, giving the same message to all the cells they meet. For sugar metabolism, the hormone messenger is *insulin*. Insulin is a protein that is made in the beta cells, which are clustered inside the pancreas. When the level of glucose in the blood becomes too high, the beta cells secrete insulin molecules into the bloodstream; thus, after a meal, the pancreas puts a large dose of insulin into the blood. The message that insulin then transmits throughout the body is "it's time to absorb, use, and store glucose." '

This paragraph contains six sentences, and its length alone should send you back to your writing desk. Reading the paragraph, you can find two major ideas. First, there are sentences about hormones in general. Second, there are sentences about one specific hormone, insulin. To emphasize each of these ideas, we should break the paragraph in two: one paragraph concerning hormones in general and the other concerning the nature and the effects of insulin:

- ‘The body uses hormones to coordinate the metabolism of its many far-flung cells. A hormone is a chemical that is carried in the bloodstream and that gives a message to the cells it contacts. For sugar metabolism, insulin is one of the hormone messengers, and its message is “take up, use, and store glucose.”
- ‘Insulin is a protein that is made in beta cells, which are clustered inside the pancreas. When the level of glucose in the blood becomes too high, the beta cells secrete extra insulin molecules into the bloodstream. After a meal, for instance, the pancreas secretes a large dose of insulin into the blood.’

In a literary work, where the ebb and flow of words conveys a subconscious emotional message, a page of short paragraphs can be choppy and disruptive. However, a research paper has a different goal. Scientific writing must present a clear unemotional experience. Here, the methodical form, *Idea #1*, breathe, *Idea #2*, breathe …, is an effective way to write.

2.2. Inside a Scientific Paragraph

2.2.1. The Lead Sentence

A typical scientific paragraph begins by stating its point, so the lead sentence should tell us the focus of the paragraph. In the two-paragraph example above, the first lead sentence, “The body uses hormones to coordinate the metabolism of its many far-flung cells,” tells us that the first paragraph is about hormones as long-distance messengers. The second lead sentence, “Insulin is a protein that is made in beta cells, which are clustered inside the pancreas,” tells us that the second paragraph is about a specific hormone, insulin.

2.2.2. The Subsequent Sentences

The remaining 2–3 sentences in each paragraph expand on the focal point that was identified in the lead sentence. Inside the paragraph, the sentences may:

- Give examples of the focal point.
- Give more details about the focal point.
- Remind readers that the focal point is a member of a more general class of similar things.
- Highlight an implication of the focal point.

In our example above, the first lead sentence tells us that the focal point of the paragraph is:

- HORMONES = LONG-DISTANCE MESSENGERS

The second sentence gives details of both sides of this equation:

- HORMONE = CHEMICAL
- HORMONAL MESSENGERS TRAVEL VIA THE BLOODSTREAM

Finally, the third sentence gives specific examples:

- INSULIN = HORMONE
- INSULIN'S MESSAGE = "TAKE UP, USE, AND STORE GLUCOSE"

2.2.3. Internal Flow

A scientist should be able to read your paragraphs without pausing. To give your writing this flow, each sentence of a paragraph should set the stage for the following sentence. Each internal sentence should be an extension of its predecessor. This can be done by making the subject or object from sentence number one the subject or object of sentence number two. By sharing its predecessor's subject or object, the second sentence continues the discussion and connects new ideas to those that have been established previously.

For example, in the first paragraph of the example above, 'hormone' is an object in sentence number one, and it is then used as the subject of sentence number two:

- "The body uses *hormones* to coordinate the metabolism of its many far-flung cells. A *hormone* is a chemical that is carried in the bloodstream and that gives a message to cells it contacts."

Likewise, 'hormone' and 'message' are a subject and an object in sentence number two, and 'message' is used as a subject and 'hormone messenger' is used as an object in sentence number three:

- 'A *hormone* is a chemical that is carried in the bloodstream and that gives a *message* to cells it contacts. For sugar metabolism, one of the *hormone messengers* is insulin, and its *message* is "take up, use, and store glucose."'

2.3. Connect Succeeding Paragraphs

In the same fashion, you can smooth the travel between paragraphs by making the lead sentence of each paragraph refer to the previous paragraph. The flow between paragraphs is most natural if the subject of the lead sentence is a subject or an object in the last sentence of the preceding paragraph. In our example above, 'insulin' makes the bridge between the two paragraphs:

- 'The body uses hormones to coordinate the metabolism of its many far-flung cells. A hormone is a chemical that is carried in the bloodstream and that gives a message to cells it contacts. For sugar metabolism, *insulin* is a hormone messenger, and its message is "take up, use, and store glucose."
- '*Insulin* is a protein that is made in beta cells, which are clustered inside the pancreas. When the level of glucose in the blood becomes too high, the beta cells secrete extra insulin molecules into the bloodstream. After a meal, for instance, the pancreas puts a large dose of insulin into the blood.'