

tific writing, and in particular the journal paper, but of course most of what you learn here will transfer to writing of almost any other kind.

Scientific writing isn't art (although it needn't be ugly, either; see chapter 28), and nobody expects your readers to swoon over the lyricism of your prose. Nevertheless, attention to style can make your writing more effective, and your reader grateful.

SEVENTEEN

Paragraphs

The most obvious unit of organization within sections is the paragraph. Paragraphs are obvious because we use line breaks, indentation, and white space to make breaks between them that can't be missed. All this typographic attention suggests that organization of material into paragraphs must be really important, and that's true. Good paragraph structure can make communication with your reader enormously clearer. This is especially true for scientific writing. True, scientific paragraphs look and function just like any other paragraphs—but because we write about material that's inherently complex and highly technical, the stakes are arguably higher than for other kinds of writing. The major focus of this chapter is on how you can use paragraph structure to make complex material as effortlessly clear to your reader as possible.

You probably decided on the rough ordering of material you need to package into paragraphs during your story-finding steps (chapter 7). What's next is to tackle actually writing those paragraphs, and connecting them so they work together.

The Nature of the Paragraph

A paragraph is a unit of logical organization best thought of as introducing and treating a single idea. Thus, each paragraph break marks the appearance of a new idea in your argument. (In this chapter's examples, I emphasize paragraph breaks by including the paragraph symbol, or pilcrow: “¶.”) What constitutes a “new idea” meriting a new paragraph can be subtle, though. A paragraph may introduce an idea that's entirely new, or it may take a new perspective on something already under dis-

cussion (for instance, shifting from advantages to disadvantages of a procedure, or from evidence supporting a hypothesis to that opposing it). It may mark movement through a sequence of related ideas:

¶Three features of the data suggest . . . First, . . .

¶Second, . . .

¶Third, . . .

Occasionally, you might even engineer an extra idea shift deliberately, so that you can give your reader a paragraph break as a breather during what would otherwise be an overlong passage. How long is “overlong”? There is, I’m afraid, no simple answer, beyond “too long for effortless and crystal-clear comprehension by the reader.” Experience (and reviewers) must be your guide.

Three Properties of Good Paragraphs

Good paragraphs have three important properties: they are unified, coherent, and distinct. All sentences in a “unified” paragraph deal with the same idea. A “coherent” paragraph has sentences that work together effectively to develop its idea. A “distinct” paragraph is self-contained, differs in topic from paragraphs preceding and following, and communicates its idea without strong dependence on other paragraphs.

Making paragraphs unified. If your paragraph is to be unified around a single idea, you need to know, and tell your reader, what that idea is. Clearly declaring the paragraph’s central idea is the job of its topic sentence. (Actually, a paragraph may have topic *sentences*: sometimes you may take two or three—but never more—to declare a topic. As you read here, just tack a mental “(s)” onto “topic sentence.”)

In scientific writing, the topic sentence is nearly always the first in the paragraph. This is one of a paragraph’s two “power positions,” where readers expect to find important information. The other is its *last* sentence, a good place for a succinct statement of the paragraph’s take-home message. When you structure a paragraph this way, you announce your destination right up front, bringing the reader along for a smooth ride to the expected finish.

A topic sentence declares the paragraph’s central idea, but does not have to fully explain it. This is a good thing, because in scientific writing a paragraph’s idea will often be complex enough that your reader won’t fully understand it without the logical development to come. Such situations can be accommodated with a topic sentence along the lines of “¶We can evaluate the cluster-assist model by considering three features of our protostar mass and distribution data.” This provides a road map to the paragraph—not with every detail, but with enough about its route to avoid any major surprises.

With the topic sentence out of the way, the body of the paragraph is devoted to development and support of the central idea, including logic, details, examples, and so on. *Every* sentence in your paragraph should contribute to developing the idea announced by the topic sentence. Deviations from this leave your readers feeling a kind of mental whiplash, wondering whether they have missed an intended connection or misunderstood the paragraph’s announced idea. For example, imagine that you read this:

¶⁽¹⁾Two main forces are at work as protostars accrete matter from clouds of dust and gas: gravity and radiation pressure. ⁽²⁾The force of gravity drives accretion, and increases as more material is accreted. ⁽³⁾Radiation pressure opposes accretion, and increases as gravitational collapse increases the protostar’s temperature. ⁽⁴⁾As accretion progresses, radiation pressure strengthens relative to gravity, and accretion should cease when the two forces balance. ⁽⁵⁾Electromagnetic forces drive stellar winds. ⁽⁶⁾The simplest models suggest that gravity-radiation equilibrium should occur before the protostar reaches about 10 solar masses. ⁽⁷⁾The existence of larger stars, therefore, suggests that these models are incomplete. ⁽⁸⁾Very massive stars are the source of elements heavier than iron in our universe.

This paragraph probably leaves you unsatisfied. Sentence 1 (the topic sentence) declares that the paragraph is about the two forces that control accretion of mass to a protostar. All seems well as these forces are identified and sentences 2–4 explain their roles. Sentence 5, though, mentions a third force, one missing from the topic sentence. Are electromagnetic forces related to protostar accretion in a way you haven’t

grasped? Or is the topic of the paragraph not “forces controlling accretion” after all? Or does the sentence simply not belong? Sentences 6–7 return to the declared topic, but sentence 8 drifts away again. The writer (me)¹ should have recognized sentence 5 as a stray thought and deleted it, and realized sentence 8 was better placed in an earlier paragraph justifying interest in massive stars. Read the paragraph again without them, and notice the difference:

¶ Two main forces are at work as protostars accrete matter from clouds of dust and gas: gravity and radiation pressure. The force of gravity drives accretion, and increases as more material is accreted. Radiation pressure opposes accretion, and increases as gravitational collapse increases the protostar’s temperature. As accretion progresses, radiation pressure strengthens relative to gravity, and accretion should cease when the two forces balance. The simplest models suggest that gravity-radiation equilibrium should occur before the protostar reaches about 10 solar masses. The existence of larger stars, therefore, suggests that these models are incomplete.

This version passes the “unity” test: each sentence relates clearly to the idea declared in the topic sentence.

Making paragraphs coherent. If the sentences that make up a unified paragraph are to work together to develop its idea, they need to present material in a logical order, and to relate each step of idea development to the next. These functions are accomplished by paragraph organization and by relational devices.

In a well-organized paragraph, material is arranged to give your reader a mental framework on which to hang all the information the paragraph offers, and so that whatever information the reader needs to understand any given sentence has already appeared in previous ones. There are two major techniques you can use to achieve these goals: signalling in the topic sentence, and adoption of a standard organizational scheme.

¹ You might think it’s difficult for me to write plausible but deliberately flawed paragraphs to serve as examples. If so, you’re confusing me with Alexandre Dumas, or maybe Barbara Cartland (Chapter 2). Believe me, plausibility might be hard work, but flawed is dead easy.

Signalling by the topic sentence can alert your reader of organization of material to come, creating an expectation that the rest of the paragraph fulfills:

Carbon-oxygen double bonds occur in ketones, carboxylic acids, and esters, but these classes differ in the groups bonded to the carbonyl carbon. In ketones . . . In carboxylic acids . . . In esters . . .

Alternatively, you can take advantage of reader expectations by adopting a standard organizational scheme. There are a number of possibilities, each of which matches a natural way that readers tend to organize their own thinking. In addition, these are so commonly used by writers that readers are practiced at following them. You might use organization that is:

- **Spatial or temporal.** This works particularly well for description: for instance, of a stratigraphic section from bottom to top, or an experimental procedure from beginning to end.
- **General to specific.** This scheme introduces a general topic and then narrows it to finer and finer detail. This is particularly effective in an Introduction (chapter 10).
- **Specific to general.** This scheme reverses the previous one, building from details to a broader conclusion. This scheme is particularly effective in a Discussion (chapter 13).
- **Least to most important.** This emphasizes the building of an argument toward the most important point in the power position at the end of the paragraph.
- **Familiar to unfamiliar.** This scheme accommodates readers’ preferences for beginning on comfortable ground, then extending themselves to the unfamiliar.
- **Simple to complex.** Along similar lines, readers prefer to deal with simple items before more complicated ones. This suggests placing rules before exceptions and simple special cases before complex models.
- **Certain to uncertain.** Contestable claims are more easily understood, and will be more fairly considered, when they are built on foundations of more settled material. You can take advantage of this by establishing conventional wisdom before showing its limitations or providing a compet-

ing new model. The forces-in-protostar-accretion paragraph above is organized this way.

In pursuit of coherence, good organization is complemented by “relational devices”: words or structures that indicate relationships between sentences. (We’ll see later that we use similar devices to connect paragraphs.) If you don’t use relational devices, you ask your reader to do the work of fitting each bit of information into the paragraph’s overall framework. That’s really a job that belongs to you as the writer. Common relational devices include:

- **Parallel construction and word choice.** The reader can be led comfortably through a sequence of material when it is expressed in a series of grammatically, linguistically, or structurally similar sentences. The most obvious example is the numbering of points in a list: “First, . . . Second, . . . Third, . . .” Less blatantly, a series of sentences can be parallel in phrasing, sentence structure, and word choice:

¶ We measured **enzyme activity** in presence of **inhibitor** with an in vitro assay. We first **purified the enzyme** in a sucrose gradient. We then **added 0.1 μmol of purified enzyme** to each well of a 96-well plate, and **added 0.1 μmol of inhibitor** to half the wells. We **incubated the plates** at 37° for 30 min, and then **added 0.1 or 1 μmol of substrate** to each well. Finally, we **assayed enzyme activity** spectrophotometrically.

Notice how each sentence takes the same basic structure, and furthermore how words playing similar functions take parallel form: the same part of speech, the same tense, voice, number, and so on.

- **Repetition.** Repeating key words or phrases can tie sentences together and also remind readers of the paragraph’s topic:

¶ We measured **enzyme activity** in presence of **inhibitor** with an in vitro assay. We first **purified the enzyme** in a sucrose gradient. We then **added 0.1 μmol of purified enzyme** to each well of a 96-well plate, and **added 0.1 μmol of inhibitor** to half the wells. We **incubated the plates** at 37° for 30 min, and then **added 0.1 or 1 μmol of substrate** to each well. Finally, we **assayed enzyme activity** spectrophotometrically.

Parallelism and repetition are complementary techniques; I used both in the enzyme-assay example.

It can be tricky to hit the right degree of parallelism and repetition. Inexperienced writers often overuse them, making passages choppy and stilted. But when this is pointed out, many writers overcorrect, making sure every sentence uses different sentence structure, voice, vocabulary, and so on. A little variety keeps your reader awake, but too much disrupts coherence: it asks readers to master, with each sentence, not just new material but also a new way of encoding that material linguistically. As in many similar aspects of the craft, you can develop a sense of how much repetition (and how much variety) is enough by paying attention to passages you admire from the work of others (chapter 3).

- **Transitional expressions.** Transitional expressions are words or short phrases that explicitly indicate the relationship of one sentence to earlier ones. Transitional expressions may be adjectives, adverbs, conjunctions, prepositions, or phrases that function in one of those ways: for example, *also*, *although*, *as an example*, *because*, *hence*, *however*, *in conclusion*, *next*, *on the other hand*, *similarly*, *specifically*, *that is*, *then*, or *until then*. (Fowler and Aaron [2011], among other sources, offers a much longer list.)

Compare two versions of this paragraph:

Without transitional expressions: “¶ Lava from the 1998 eruption was richer in metals than that from the 1983 or 1977 ones. The 1998 lava was denser and less CO₂-rich. Ejecta volumes were very similar. We cannot reject the hypothesis that eruptions are driven by periodic filling of a single magma chamber.”

With transitional expressions: “¶ Lava from the 1998 eruption was richer in metals than that from the 1983 or 1977 ones. The 1998 lava was, **furthermore**, denser and less CO₂-rich. **Despite these differences**, ejecta volumes were very similar. **As a result**, we cannot reject the hypothesis that eruptions are driven by periodic filling of a single magma chamber.”

The two versions contain exactly the same information, but the second is much easier to understand because the transitional expressions draw strong connections between different bits of information.

Making paragraphs distinct. Paragraphs should be logically distinct: each with its own topic, and each providing a complete and self-contained treatment of that topic. The meaning of “complete and self-contained” is a bit subtle, though. Each paragraph you write should announce a new topic (or a new angle on a larger topic) and then bring its development to some conclusion. But this certainly doesn’t mean paragraphs are independent, as is frequently claimed. If you’re writing about something even the slightest bit complicated, your readers’ understanding of each paragraph will depend on their assimilation of earlier ones. Not only that, but paragraphs need to work together in building your manuscript’s larger argument. So a new paragraph should neither represent a whole new train of thought nor just continue its predecessor’s. It should take the train onto a new track—but a new track that’s part of the same overall journey.

For paragraphs to work together despite their distinctness, readers need to understand how each relates to the one before. Techniques for linking paragraphs are essentially the same as those for linking sentences within paragraphs: logical arrangement of paragraphs within sections, parallelism in structure and wording, repetition, and transitional expressions. The tricky part is that these linkages should be strong enough to ease the reader’s flow through the argument, but not so strong that distinctness is compromised. Linkages that are too strong are common. This problem usually take one of three forms:

- **Superfluous paragraph breaks.** Sometimes a writer will feel a paragraph is getting too long and try to fix the problem by introducing a paragraph break—without actually engineering a shift in topic. This mistake is easy to recognize, because the content of the second paragraph will belong to the topic declared by the first. If you want to divide a paragraph, you need to clearly divide its topic.
- **Overstrong dependencies.** A paragraph may start with a pronoun or transitional expression that doesn’t just *link* it to the preceding paragraph, but makes the meaning *entirely dependent* on it. For example, a paragraph might open “**¶Despite this**, it remains clear that . . .,” or “**¶For example**, Devonian trilobites . . .” Either of these constructions would nicely connect sentences within a paragraph, but at the begin-

ning of a paragraph each demands reference to information that is not there.

The solution to overstrong dependencies is to name both halves of the linkage in the linking sentence. You can replace a pronoun with repetition of its antecedent: “**¶Despite the difference between replicate experiments, it remains clear that . . .**”), or add a brief reminder of the preceding paragraph to fill out the transitional expression: “**¶Devonian trilobites provide a good example of a declining lineage . . .**”

- **Redundant paragraphs.** A section may include two paragraphs (adjacent or not) that treat substantially the same topic. This adds unnecessary length (chapter 21) and also creates confusion: readers who expect distinctness will wonder what they are missing.

Organizing Paragraphs into Sections

With the assembly of sentences into paragraphs under our belts, we can zoom out just a little to revisit the assembly of paragraphs into sections. In chapter 7, I pointed out that the topic sentences of each paragraph constitute a kind of outline that you can use to plan the telling of your paper’s story. There I largely ducked the issue of how to arrange these points to make a smoothly building argument. Now I can be a bit more explicit: all the techniques that build sentences into coherent paragraphs can also help build paragraphs into coherent sections. Sections flow well if paragraphs are arranged spatially or temporally, from least to most important, from simplest to most complex, and so on. Parallelism among paragraphs in structure or repetition of wording favors overall coherence too.

An especially important form of parallelism in scientific writing is consistency in paragraph order from section to section. Often, you will include analogous sets of paragraphs in Methods and Results, in Results and Discussion, or in Introduction and Discussion. Arranging paragraphs in the same order in each section allows your later sections to take advantage of reader expectations established by the earlier ones.

While planning the organization of paragraphs into sections is one major goal of outlining, don’t forget that it’s quite normal for your story

to change as you develop the outline into a manuscript (chapter 5). Expect, therefore, to revisit the order and organization of paragraphs as you write and revise.

Chapter Summary

- A paragraph introduces and treats a single idea.
- Good paragraphs are *unified*, *coherent*, and *distinct*.
- A paragraph is unified when all content relates to the idea declared in its topic sentence.
- A paragraph is coherent when it develops an idea in a logical order with each step related to the next.
- A paragraph is distinct when its treatment of an idea is complete and self-contained.
- Just as sentences are assembled into paragraphs, paragraphs are assembled into sections; the same guidelines apply.

Exercises

1. Choose a recently published paper in your field, and from it choose two consecutive paragraphs in either Introduction or Discussion.
 - a. What is the central idea of each paragraph?
 - b. Are the two paragraphs distinct? How?
 - c. Are they connected by relational devices?
2. Now focus on a single longish paragraph (at least eight sentences).
 - a. How is material organized within the paragraph (e.g., spatially, temporally, general-to-specific, least to most important)?
 - b. Rewrite the paragraph twice, with the same content, but each time with a different organizational scheme. Which of the three versions (including original) is most effective? Why?
 - c. In the original, identify some relational devices that lead the reader through the paragraph. In your rewritten versions, what relational devices did you use?

EIGHTEEN

Sentences

My discussion of paragraphs (chapter 17) presumed a basic familiarity with their building blocks: sentences. This wasn't too desperate a leap, as by the age of two or three, most children can produce simple but recognizably structured sentences. *Mastery* of sentence construction is another matter. English provides a bewildering variety of ways to build more and more complex sentences, which is why one standard composition book (Fowler and Aaron 2011) allots 259 pages to sentence construction. Most scientific writers experience at least occasional difficulties. Partly this is for the same reason I emphasized in considering paragraph structure: our subject matter is complex. In addition, some issues (involving tense and voice, for instance) are specific to scientific writing.

Grammar

Tackling sentence construction means confronting something that inspires in many scientific writers either boredom or loathing: grammar.

Those of us with English as a first language often remember being hectorered mercilessly in high school about the rules of English grammar. "Never end a sentence with a preposition," we were told, "and never start a sentence with 'And.'" Writers newer to English (see chapter 27) usually discover similar advice in courses, books, and online guides. The thing is, while this advice (and a lot more like it) is nearly universal, it's also wrong. It's wrong in detail—sometimes "And" is just the right way to start a sentence—but more important, it's wrong in concept. If you see grammar as a long list of rules for distinguishing "correct" sentences