Exercises

1. Choose a recently published paper in your field, and read the Introduction. Highlight text comprising each of the three main Introduction components (establishing territory, establishing niche, occupying niche).
2. How would you change that paper's Introduction for publication in a journal of narrower scope? One of wider scope?

ELEVEN

The Methods Section

Methods sections are relatively straightforward to write. They outline the materials you used and the procedures you followed in executing your study and analyzing your data. Often, you can model substantial portions after an earlier paper in which you reported similar work or adapt text from a grant proposal. And most, if not all, of the Methods can be written while you're planning or conducting the research, when the procedures are fresh in your mind. Despite this section's relative ease, however, three issues can be troublesome: organization, level of detail, and avoiding self-plagiarism.

Organizing the Methods

It's tempting to organize a Methods section chronologically, recording what you did in the order that you did it. This might be the right way to write a travelogue or an autobiography, but it's the wrong way to write a scientific paper! Your experience in doing the research doesn't matter; what does is your reader's need to understand it.

There is no one-size-fits-all recommendation for organizing Methods to make them easily understood. One possibility is a three-part presentation of background, experiments or observations, and analysis. This organization begins with material that sets the stage for the main procedures, such as descriptions of your field sites, materials and equipment, methods for selecting subjects, or calibrations or control procedures intended to demonstrate that your procedures work as expected. The second subsection describes your experiments and the data you collected.

The final subsection outlines how you analyzed the data, and how those analyses can answer your research question. This might include such things as the quantities you calculated from the raw data, comparisons you made, or relationships you sought among variables, and the statistical procedures you used to assess any patterns you found.

The background-experiments-analysis organization, though, becomes cumbersome in more complicated papers. If answering your research question involves combining several different lines of investigation (perhaps theoretical and experimental work, or several distinct sets of observations), it's usually better to work though each procedurally distinct component of the work separately. For instance, the story-summary outline for our star-formation paper (chapter 7) included a three-component summary of the observational Methods. With a fourth component added to integrate data from the first three, we have:

- *Determining protostar rotational velocities*
- *Determining protostar masses*
- *Determining nearest-neighbor distances*
- *Testing whether massive protostars always have close neighbors*

An effective Methods section would follow this outline, with four subsections (likely following a few sentences summarizing the overall approach). Each subsection could separately follow the background-observations-analysis organization above: the first, for instance, would specify the nebulae observed, describe the instruments used to measure red/blue shifts of the ^{13}C emission line, explain how those shifts were measured, and outline how rotational velocities were calculated from the shifts. This organization works because the four subsections are logically separate, but each builds on the ones before. (Mass determination, for instance, relies on the results of the rotational velocity measurements.) An alternative arrangement introducing instrumentation for all components, then describing all the observations, and finally dealing with data analysis would force the reader to shift attention repeatedly from velocities to masses to distances and back again.

Whatever organization works best for your Methods, it's a good idea to signal it clearly with a system of subheads. (The four bullets above would work well for our star-formation paper.) Subheads enhance your paper's finding system, orienting the reader with respect to the larger argument and identifying components that can be tackled and digested relatively independently. It's especially effective to match subheads in the Methods with identical subheads in the Results, so that the reader can easily navigate back and forth.

Appropriate Detail

In writing your Methods, you must decide how much detail to supply for each procedure. Getting this right can be tricky. Some details must obviously be included: for instance, journals nearly always require mention of ethics-board approvals for work involving human subjects. Other details should obviously be omitted: whether you took your notes with a 2H or HB pencil is utterly unimportant (although, believe it or not, I've seen manuscripts specifying this). Between these extremes is a long continuum of relevance and plenty of grey area.

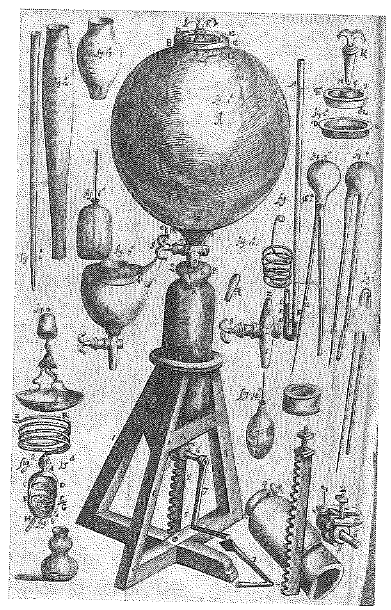
How do you decide whether to include or omit a given detail? Experts offer different answers to this question because they disagree about the function, for the reader, of the Methods section—a function that has evolved considerably over the last 350 years (Box 11.1). Most writing books (e.g., Katz 2006, Day and Gastel 2006) tell you to give readers enough detail so that they could repeat your work and verify the results themselves. However, studies of the way scientists *actually* write find that few published papers come close to this level of detail (e.g., Swales 1990, Gross et al. 2002). (The main exception to this generalization is the "methods" paper, in which providing new methodology for others to repeat is the major point.) These studies suggest that your Methods section is best seen as establishing the credibility of your approach, and thus giving readers a reason to believe your findings. In other words, "if critical readers judge . . . [the Methods] a plausible strategy for solving the problem stated in the Introduction, then they will likely view the article as authentic science" (Harmon and Gross 2007, 193). In addition, the Methods tell readers what they need to know about the procedures if they are to understand the Results.

Box 11.1 Replication, witnessing and authority: the evolution of the Methods

The past 350 years have seen considerable evolution in the way methods are communicated, which reflects underlying evolution in the *reason* for relating those methods. This evolution accounts for much of the modern disagreement over the level of detail Methods sections should include.

Scientists working at the birth of modern scientific communication, in the seventeenth century, belonged to the intellectual tradition of the European Renaissance. They believed learning should come from empirical observation rather than from study of earlier texts (as in the medieval "scholastic" tradition). But as science progressed, it became more and more obviously impossible to make progress without building on results reported by others. So how could those reports earn authority?

This question was a major concern for Robert Boyle, the pioneer of the modern scientific paper in the 1660s (chapter 1). Boyle's answer was threefold (Shapin 1984). First, he favored exhaustive detail of equipment and procedures, so that readers could repeat his experiments for themselves. Second, Boyle argued for "communal witnessing": if one was to rely on the results of others, then those results must be witnessed by other scientists. Thus, many of Boyle's key experiments were conducted in public, and Boyle published the names and qualifications of his witnesses along with his results. Third, Boyle described in exhaustive detail not just his methods, but his experiments' circumstances and settings, his false starts and failures, and much else. Illustrations of his experimental apparatus were detailed and realistic depictions, not simplified line drawings. For example, to accompany his reports of experiments using his famous vacuum pump (Boyle 1660), he provided an illustration of the *particular* pump he had used, complete with irregularities,



dents, and dings. The point of all this description was to make readers feel as if they had been there—to recruit them as "virtual witnesses" (Shapin 1984).

This approach was widely adopted. A spectacular example is Pierre-Louis de Maupertuis' (1737) account of an Arctic expedition to measure the Earth's shape. Maupertuis spends many pages relating the excitement and hardships of his travels. He describes, among other things, the midnight sun, the assaults of biting flies, techniques for defense against kicking reindeer, and cold that left only his brandy unfrozen to drink.

None of Boyle's three answers to the authority problem proved fully satisfactory. Few others ever tried to repeat his experiments. Communal witnessing was cumbersome and inefficient. Virtual witnessing had more to do with rhetoric than logic, and it made publications verbose and unwieldy. It was gradually abandoned.

By the mid-nineteenth century, the professionalization of science led to a new kind of authority. A report began to be considered reliable not because it was repeatable, witnessed, or detailed, but instead because its author belonged to a community of established scientists and had professional credentials and/or an institutional affiliation. Along with this came an emphasis on detachment and objectivity in writing, which meant depersonalizing and simplifying the Methods (Daston and Gallison 2007). Authority also came from peers recognizing a scientist's use of standard or appropriate methods. In the early twentieth century, peer review became standard; it gave reports further authority because they had passed muster with experts who consider appropriateness of method, but almost never attempt to repeat it.

In modern science, repeatability and witnessing both survive, but their role lies largely in testing extraordinary claims such as cold fusion (Fleischmann and Pons 1989) or hyperdilution memory of water (Davenas et al. 1988). Professionalism is now the major grounds for the authority of most published work, which explains why cases of scientific fraud are always shocking and often slow to be discovered. (For instance, the psychologist Diederick Stapel falsified data for at least fifty-five publications before his misconduct was identified [Stapel Committee 2012]). Fortunately, fraud appears to be relatively uncommon—estimation is difficult, but between 0.001 percent and five percent of scientists appear to have falsified data at least once (Fanelli 2009)—and seldom distorts accepted understanding for long. This suggests that the lack of emphasis on repeatability is not a major handicap to the progress of science.

Thinking of the Methods as establishing credibility suggests that a detail merits inclusion if it fulfills one of three slightly different functions. First, it might establish your qualification as a researcher (that you know how to use standard methods in appropriate ways). Second, it might establish the plausibility of your approach to the problem (that you are gathering relevant data and analyzing it in a way that sheds light on your research question). Third, it helps establish your sequence of investigative steps, so that the reader can understand the logical basis for claims to come in your Results and Discussion. A simpler expression of this might be that a detail should be included if, and only if, it could influence the reader's interpretation of your Results.

Take a real example[1]. A student of mine, Chris Kolaczan, studied genetic variation in a parasitic wasp, one that attacks a caterpillar living inside a gall on the stem of a goldenrod. Chris's published Methods section (Kolaczan et al. 2009) covers field collection and preservation of the wasps, DNA amplification, fragmentation, fragment-length determination in the laboratory, and analysis of the resulting data. It includes the following sentence:

> At each collection site, we collected and opened . . . galls, removing the [caterpillars] and inspecting them for the presence of . . . [parasites]. Parasitized [caterpillars] were immediately preserved in 95% ethanol.

Here, Chris describes opening galls and identifying parasitized larvae. This contributes to the plausibility of the approach and gives the reader enough knowledge of the series of investigative steps to understand Chris's results. For instance, it matters that each wasp analysed came from a different caterpillar in a different gall. For someone looking to repeat the work, though, a lot is missing. The collection sites are located (by an Appendix) only to within about 1.5 km, and Chris doesn't specify how to recognize a galled plant, open a gall, or distinguish a parasitized caterpillar from an unparasitized one. Chris also mentions that preservation was immediate and done with 95% ethanol, establishing that he used standard protocols to adequately preserve tissue for DNA analysis. That is, Chris attests that the reader needn't worry about

[1] While I've been enjoying my star-formation example, engaging too closely in the details of that hypothetical study risks revealing that I don't actually know very much about the topic. We wouldn't want that.

some obvious problems that might compromise interpretation of the results (for instance, artifacts arising from degradation of DNA before analysis). These preservation details are not necessary for someone to repeat the work (because alternative methods, such as freezing in liquid nitrogen, would be equally suitable), but they contribute to credibility. Chris *doesn't* mention the containers in which preserved larvae were held (4 mL polypropylene vials, actually), because it's hard to imagine a reader's reaction to the study depending on whether larvae were kept in plastic vials or glass ones (or coffee cups, for that matter). Overall, this Methods section did not provide enough detail for someone to repeat the work exactly, but it did establish Chris's authority as a scientist, the plausibility of the approach, and the sequence of investigative steps. As a result, readers should find the results credible and understandable.

The credibility criterion for inclusion of detail is less cut-and-dried than the repeatability criterion, but it can be applied with some careful thought and familiarity with the literature. Reading published papers in your field is enormously helpful, because each field (and sometimes each journal) has conventions for the level of detail expected in Methods. For example, in ecology it's standard practice to identify the software package used for statistical analyses, but in cell biology, this detail is rarely reported. While these conventions can seem arbitrary, noticing and following them helps you meet reader expectations and build credibility.

What of a reader who actually does want to repeat your experiment? Such readers are important, but very rare: a vanishingly small fraction of published studies are ever exactly replicated by another scientist (Casadevall and Fang 2010, Loscalzo 2012)[2]. Let us imagine, extremely generously, that one percent of your readers want to repeat your work using your methods; the rest want only to be assured of the credibility of your results. Providing the wealth of detail desired by the one percent would reduce clarity and increase reading effort for the vast majority. And it wouldn't make repetition more likely anyway: its infrequency has little

[2] If scientific results aren't routinely verified by repetition, how are they verified? Many never are, and in this collective shrug science indicates its opinion of their importance. The rest are verified because their results prove consistent with other results, and because other scientists are able to build further understanding on top of them.

to do with writing style, and much to do with the time and expense required to replicate work and the lack of professional rewards for doing so. Very detailed procedures can be provided in an online supplement (chapter 14), or can simply be omitted, because would-be repeaters can contact an author for further detail.

Avoiding Self-Plagiarism

It's common to find yourself writing multiple papers that use the same methods or study system. Most scientists easily recognize that reusing the same data or analyses in multiple publications is inappropriate, but what about reusing descriptions of one's Methods? Writers are sometimes surprised to learn you can model new text after old, but that simply reusing old Methods text is a form of plagiarism. If you're skeptical about this, consider Wei et al. (2010), which was retracted by the journal, over the authors' objections, after a reader noticed substantial repetition of Methods (and Results) from an earlier paper (see Retraction Watch, http://bit.ly/1SaJBTy).

Plagiarizing yourself is something of a tricky concept. You can't steal your own silverware, so how can you steal your own words? Well, you may own your silverware, but you usually don't own your published words—instead, copyright tends to be assigned to the journal's publisher. Legally, therefore, you are no more free to reuse your own words without permission than you are to reuse mine. (In contrast, reusing words from a grant proposal is perfectly legitimate, as proposals are not considered published.)

When you need to describe a procedure again, and can't repeat a previous description, you can use one of two techniques. Sometimes a later paper can include only the bare bones of a method, citing your older work for more detail. This might be the case, for instance, when the first paper describes a novel technique, but the second need only assure its readers that a technique is available. More often, though, you'll want to repeat some detail because you can't expect readers to dig out your previous papers to understand your latest one. Then you will have to rephrase your earlier Methods. Fortunately, English is a rich enough language that there is never just one good way to express something. As an

example, these short passages come from the Methods sections of two papers that needed to introduce their readers to the same study system (a pair of goldenrod species and the insects that feed on them):

> The goldenrods *Solidago altissima* and *S. gigantea* are clonal perennials codistributed over much of eastern and central North America. Intermixed stands of the two species are common in open habitats such as prairies, old fields, roadsides, and forest edges. Individual ramets grow in spring from underground rhizomes, flower in late summer and fall, and die back to ground level before winter. . . . *S. altissima* and *S. gigantea* are attacked by a diverse fauna of insect herbivores, which vary in diet specialization (Heard 2012; citations and a few details removed for clarity).

> The goldenrods *Solidago altissima* and *S. gigantea*, two closely related members of the *Solidago canadensis* complex, share a diverse herbivore fauna. *S. altissima* and *S. gigantea* are abundant and frequently syntopic in prairies, old fields and disturbed habitats across much of temperate North America. They are long-lived rhizomatous perennials, with new ramets growing from overwintered rhizomes each spring, flowering in late summer to fall, and senescing to ground level in late fall (Heard and Kitts 2012).

Comparing the two passages, notice three things that helped us avoid self-plagiarism. First, each includes a slightly different set of details about the system. This is partly because different details were important to the two papers (variation among herbivores in diet specialization was central to the first paper, but not to the second); but it also helps keep the writing fresh. Second, the information is ordered differently, something that would be even more apparent from longer passages. Third, even where the same information is presented, the words and phrasing are fairly different.

Chapter Summary

- Methods have many possible organizational schemes, but a chronological narrative is rarely effective.
- Sources disagree on the detail necessary in Methods because they disagree on the section's function.

- Most readers will not try to reproduce your work; therefore, it is not necessary (or wise) to provide the level of detail necessary for someone to repeat your experiments exactly.
- A detail should be included in Methods if it (a) establishes your qualifications as a researcher; (b) establishes plausibility of your approach to the problem; or (c) helps establish the investigative steps so a reader can understand your solution of the problem.
- You may have to rewrite Methods text from paper to paper, because you can't repeat your own published wording without copyright issues.

Exercises

1. Take an experiment (or observation) that you've planned or recently completed, and write two versions of Methods text to describe it. In the first version, include enough detail that another scientist could reproduce your work exactly. In the second, include only enough for readers to understand your work and find it credible. Which version seems closer to the Methods sections you see in the literature for your field?

TWELVE

The Results Section

Writing the Results seems as though it should be easy. Its contents certainly seem obvious: this is where you report the results of your experiments (or observations, or theoretical work). True enough; but this isn't a very useful way of thinking, because it emphasizes the writer's experience, not the reader's. Writers who take this perspective produce manuscripts bulging with preliminary results, multipage tables, dozens of complicated graphs, and every data point from every experiment they ever ran. The rare reader who sticks it out is left torn between bewilderment and resentment—and this isn't where you want *your* reader to be. So remember the importance of finding and telling your story (chapter 7), and strip your Results down. Show only the data the reader needs to understand and accept the answer you're presenting to your central research question. What remains will be a short and simple section in which every word, graphic, and data point contributes directly and obviously to telling your paper's story.

With content set, what remains is presentation. The Results section must tread carefully in its relationship to the Methods that precede it and the Discussion that follows. It must be organized so its most important content is easily apparent to the reader. Finally, it needs to communicate complex and heavily quantitative information while remaining easy to read.

Methods, Results, and Discussion

The strict separation of Methods, Result, and Discussion can seem forced. It might seem easier, and more natural, to write "I did this, and