CHAPTER 4

Reading and Writing Research Reports

4.1 Research Journals and Their Readers

An important first step for any new researcher is to become familiar with the primary journals in the field, for as we've discussed, these professional publications represent the principal medium through which individual scientists share their theories and results with others in the scientific community. The easiest way to identify the essential journals in your field is to notice those around you. Start by paying attention to what other researchers—your professors, teaching assistants, other students—are reading. When you are assigned research articles to read in your classes, take time to notice where and when the papers were published, what institutions the researchers represent, and what granting agencies provided funding for the research. Identifying the professional associations or institutions that sponsor the journals will help you understand who reads them. Most journals are quite explicit about their audiences and goals, posting editorial goals and guidelines on their websites and publishing them in their print issues as well (in every issue or in one issue annually). For example, dozens of journals are published in the field of physics, each intended for a specific segment of the physics community. The American Physical Society (APS) publishes seven *Physical Review* journals, reporting research in subfields such as atomic, molecular, and optical physics (*Physical Review A*) and nuclear physics (*Physical Review C*). The APS also publishes the prominent *Physical Review Letters*, "providing rapid publication of short reports of significant fundamental research in all fields of physics" (http://publish.aps.org/about). Beyond the needs of researchers, the *American Journal of Physics*, published by the American Association of Physics Teachers, addresses "the instructional and cultural aspects of physical science" (http://scitation.aip.org/ajp/masthead.jsp), and *Physics Today* (www.physicstoday.org) is a semi-popular magazine intended for a broader readership as well as for professional physicists. As in other areas of science, publications in physics have evolved to support the informational needs of researchers, educators, hobbyists, and others interested in the subject matter of physics and in the advancement of this area of science.

To stay active in a research field or interdisciplinary area, then, scientists need to be aware of the purposes and intended audiences of the journals published in that area. This knowledge helps them decide which journals they will want to find time to read (of the thousands in publication); and, equally important, it helps them decide where they should submit their own work for publication. Choosing an appropriate journal is a critical step in the publication of a scientific paper, for the ultimate influence of a paper in the scientific community may be significantly determined by the journal in which it appears. In science as in other domains, the amount of attention an announcement receives is to some extent determined by the context in which it appears, that is, by where, when, how, and to whom the announcement is made (Miller 1992). A researcher's decision about where to submit his or her paper ultimately determines who will have access to the work.

As a case in point, Chapter 10 includes reports of a research project headed by Dr. JoAnn Burkholder, an aquatic botanist at North Carolina State University. In 1988, Burkholder's team discovered a new genus of algae, a "predatory" dinoflagellate that kills fish by releasing a lethal neurotoxin into the water. In a series of studies over the next few years, Burkholder and her colleagues determined that the alga was responsible for massive fish kills in estuaries along the southeastern coast of the United States and was very likely associated with fish kills in other regions as well. The striking nature of the finding (this was the first known instance of predatory behavior among such organisms), along with its potential international ramifications, warranted submission of the results to the British journal *Nature*, which has a broad, interdisciplinary, and international readership. Published in *Nature* in 1992, this first major paper from the project announced the discovery of the new organism, described its behavior, and briefly listed related fish kills that had been observed. In contrast, subsequent papers focused more narrowly on the results of individual studies of the organism in the lab and in particular estuarine locations. For these later reports, the researchers targeted more specialized audiences within the marine ecology community, publishing in such forums as the *Journal of Plankton Research* and the *Marine Ecology Progress Series*.

ERCISE 4.1

Visit the websites, or obtain hard copy of three prominent journals or magazines in your research field.[1] Browse these sites or print texts to determine the purposes and intended audiences of each of these publications. Look for the publisher's description of each journal, typically found in the masthead section inside the front cover or under an "About" tab at the journal's homepage. Also peruse the editorial guidelines provided. How do these publications differ? What needs or interests in the research or broader community does each journal address? As you envision your own future as a scientist, which of these publications would you be most likely to read or to publish in? How would the articles you read in, or write for, these publications differ?

[1]For a large sampling of editorial guidelines, see http://mulford.meduohio.edu/instr/index.html. At this site, the library of the Medical University of Ohio has assembled links to the editorial websites of more than 3500 journals in the health and life sciences.

4.2 Argumentation in Science

Given the critical role of the research report in the development and exchange of scientific knowledge, it is important to understand its distinctive features and the common strategies scientists use in writing and reading these documents. Research reports in scientific journals are variously referred to as *journal articles, papers*, or *reports*. In this text, we use these terms interchangeably to designate the class of texts reporting original results or theoretical developments in professional research journals. Our purpose in this chapter is to describe some of the general conventions research reports follow and to help you analyze the specific conventions governing reports in your field.

The communication of research results is far from straightforward. It is traditional to think of scientific reports as purely factual or explanatory, but as we saw in Chapter 1, the report also serves an important interpretive and persuasive function. Scientists publish descriptions of their research not simply to tell others what they've done but also to persuade readers that the work is valid and useful. In terms of form, then, the research report is more than a narrative; it is a careful argument. The authors of a research report find themselves in the position of building a case for their research, not simply recounting actions and observations.

From this perspective, the research report represents an extended argument in which researchers seek to convince readers that their research questions are important, their methods were sensibly chosen and carefully carried out, their interpretations of their findings are sound, and their work represents a valid contribution to the developing knowledge of the field. These basic goals are clearly reflected in a common research report format, which consists of four standard parts or sections: introduction, methods, results, discussion. Each section of the report contains an argument, and each section plays a part in supporting the larger argument of the whole.[2] This structure, sometimes referred to as the *IMRAD* format, is the dominant pattern in modern science journals (Gross et al. 2002; Mackenzie Owen 2007). It is codified in editorial guidelines and science writing guides (Olsen and Huckin 1991; M. Katz 2006; Day and Gastel 2006) and is frequently introduced to students via various forms of the lab report in college courses (Carter, Ferzli, and Wiebe 2004; LabWrite 2004; Lerner 2007).[3] The basic elements of the IMRAD form are summarized by the Council of Science Editors (CSE 2006) in Figure 4.1.

[2]Notice that we use the term *argument* in the sense of "case building" here, as opposed to the everyday sense of "confrontation" or "debate." Thus, the question "What is your argument?" means "What is your line of reasoning?"

[3]An excellent online resource for learning to write lab reports is the LabWrite program sponsored by NSF and developed at North Carolina State University: http://www.ncsu.edu/labwrite/.

ctions of a Research Report: Typical Headings and Functions

adings for sections	Function of section; comments
roduction	Describes the state of knowledge that gave rise to the question examined by, or the hypothesis posed for, the research. States the question (not necessarily as an explicit question) or hypothesis. A review of existing literature also may be found in the introduction.
ethods and Materials	Describes the research design, the methods and materials used in the research (subjects, their selection, equipment, laboratory or field procedures), and how the findings were analyzed. Various disciplines have highly specific needs for such descriptions, and journals should specify what they expect to find in a methods section.
esults	Findings in the described research. Tables and figures supporting the text.
iscussion	Brief summary of the decisive findings and tentative conclusions. Examination of other evidence supporting or contradicting the tentative conclusions. Final answer. Consideration of generalizability of the answer. Implications for further research.
eferences	Sources of documents relevant to elements of the argument and describing methods and materials used.

IGURE 4.1 Sections of a research report as described by the Council of Science Editors (CSE 2006, p 464).

As the descriptions of these sections indicate, the IMRAD format consists of two sections in which the new study is actually described (methods and results), framed by two sections that place the new work in the context of previous knowledge (introduction and discussion). Both of these "framing" sections describe the current state of the field's knowledge. The introduction describes the state at the start of the report—the state that created the need for the study—and the discussion describes the new state of the field's knowledge at the end of the report—now that the new results have been added to the knowledge base.

The distinction between framing sections and describing sections is often signaled by verb tense: framing sections usually use present tense to describe the field's current knowledge ("Factors that limit the distribution of the cougar *are* not known entirely but *include* climatic features, availability of prey, and habitat features"), whereas describing sections typically use past tense to describe actions already taken and data already recorded ("We *searched* for cougar tracks between December and April each year"; "Summer and winter home ranges for individual females *overlapped* extensively").[4] In an extensive analysis of verb tense patterns in research reports, Hawes and Thomas (1997) found that writers frequently use past tense to describe particular examples in

[4]Quoted sentences from Ross and Jalkotzy (1992, p 417, 418, 419). Italics added.

support of generalized trends, whereas present tense is used when stating the generalizations themselves. One of the effects of past tense, then, is to localize and limit findings to particular researchers or labs, whereas present tense identifies a claim or conclusion as part of the field's current understanding.[5]

EXERCISE 4.2

Choose two or more full-length research reports from your field or from those included in this text. In each major section of the paper, circle the main verb in the first 10 or 12 sentences. Note whether and how verb tense shifts across sections and whether and how these verbs tend to localize findings or incorporate them into general knowledge claims.

4.3 The Logic(s) of Scientific Inquiry

We have included in this text three journal articles that follow the traditional IMRAD organizational pattern: Graham et al. (1992) and Chiba et al. (2002) in Chapter 9, both reporting clinical studies of treatments for the stomach bacterium *Helicobacter pylori;* and Burkholder et al. (2005) in Chapter 10, which examines methods for assessing toxicity of *Pfiesteria*, the "fish killer" dinoflagellate. The IMRAD format is a natural choice for reporting results from these studies, for in each case the research involved posing a question, choosing and carrying out experimental procedures, interpreting the resulting data, and drawing some conclusions about the significance of the outcome. Thus, the IMRAD format mirrors the basic logic of scientific method. Not surprisingly, this form is common in many scientific fields.

However, the emphasis on experimental methods and the presentation of new data in the IMRAD form are clearly unsuitable for papers reporting theoretical or historical research, in which the primary goal is to present new interpretations, theories, or models for understanding phenomena previously observed (Harmon 1992; Miller and Halloran 1993). Much of the research conducted in fields such as astrophysics, evolutionary biology, and geology, for example, is best described as theoretical or historical rather than experimental. Research in these areas may involve some data collection (e.g., core samples or satellite observations), but frequently the primary goal of such research is not to test hypotheses but to formulate hypotheses—to propose theories or models that account for the field's observations to date.

[5]You are already quite familiar with the effects of present and past tense verbs, for you use these distinctions in everyday conversation. Compare the statement "I mowed the lawn myself" with "I mow the lawn myself." The first sentence clearly refers to a specific occasion on which you mowed the lawn (a localized event), whereas the second refers to a general practice you've adopted (a recurring or general pattern).

The structure of papers in the historical and theoretical sciences therefore tends to be more variable than that of experimental papers. As a case in point, skim the section headings of the *Geology* paper by J. Z. de Boer and colleagues (2001) on pages 326–329 and the *Clinical Toxicology* paper by Spiller et al. (2002) on pages 330–337. Written by members of the same multidisciplinary research team and reporting on the same project, these papers nevertheless follow different organizational logics. Both begin by introducing the geographic location and history of the Delphic oracle. The researchers have compiled evidence that a gaseous vent was present in the ancient temple at Delphi and was responsible for intoxicating, and thus "inspiring," the legendary priestesses who spoke prophecies there. After the introductory sections, the *Geology* article devotes separate sections to the tectonic setting, evidence of springs in the area, and analyses of gases present. Each of these sections incorporates both historical information and the results of the team's recent field survey and water sampling. In contrast to the IMRAD form, the survey and sampling methods are described briefly in each of the above sections; there is no separate section devoted to methodology, and few methodological details are included. This primary emphasis on observations or results over methods is common in geology reporting and consistent with the descriptive nature of this science.

The second report of the Delphi research—Spiller, Hale, and De Boer's *Clinical Toxicology* article—is organized somewhat differently. Though this article reports basically the same information as the *Geology* report, the historical background is treated as evidence in this report and the authors explicitly state their intention to defend the gaseous vent theory, an ancient theory that had long been dismissed as myth. After the introduction and an overview of the controversy, the paper devotes separate sections to each of three types of evidence the authors have compiled: historical, geological, and chemical. The paper does not follow a predetermined form but is organized to highlight the critical components of this particular argument.

Notice that all the report structures discussed above provide explicit opportunities for authors to describe the assumptions and implications of their theories, in a sense the "methods" and "results" of theoretical work. It is also important to notice that these papers provide clearly announced introductory and concluding sections or paragraphs that contextualize the argument just as the introductory and concluding sections do in the conventional IMRAD form. In stating the purpose of the study, the introduction lets readers know what kind of research is to be presented. The American Institute of Physics *Style Manual* explicitly reminds authors that the type and scope of the work, whether theoretical or experimental, should be clear from the introduction (AIP 1990).

In short, all research reports will include a framing introduction and discussion/conclusion (labeled or unlabeled), but the form of the body of the paper, the actual description of the work itself, will be determined by the type of work to be described. Because written texts communicate not only facts and observations but also the ideas and logic of their authors and their fields, texts will take different forms in different research communities. You will want to notice how reports in your field tend to be organized and how that organization compares with the organizational logic of the IMRAD form that we discuss here. As you read, pay

close attention to the purpose and logic of each section. Notice how authors in your field convince readers of the need for the study and the significance of the outcome, as well as how they describe the methods, assumptions, and observations that serve as the evidence in their arguments.

In the next sections of this chapter, we describe the logic of each of the standard IMRAD elements in more detail.

EXERCISE 4.3

Read the research report by Etiope et al. (2006) in Chapter 11 and examine its organizational logic. What methods are described in this report, and where are they described? What results are reported, and where? Describe the function of each subsection and the overall logic of the report.

4.4 Introducing the Research Problem

All research reports begin with an introduction of some sort, no matter what structure is followed in the rest of the paper. This is where you explain your research objectives, argue that the research is important, and place your study in the context of previous research. As Figure 4.1 demonstrates, editors and other readers expect the opening paragraphs of a journal article to describe the state of knowledge that motivated the research in the first place and to introduce the purpose of the study. We have referred to this opening section as a "framing" section above, to underscore its role in establishing a context or framework for interpreting the new research. To examine this framing more closely, take a minute to read the scrambled introduction in Figure 4.2. In what order do you think these sentences originally appeared? Rearrange the sentences to create a coherent paragraph that would clearly establish the purpose of the research it introduces. (Jot the sentence letters in an appropriate sequence in the margin before reading on.)

In unscrambling this intro, many of you probably chose to start the paragraph with sentence A, C, or D, presumably because you felt some background or announcement of the topic was warranted at the beginning, or perhaps because you were following the familiar "funnel" introduction pattern, which starts with a broad statement of the general topic and then narrows to the particular issue at hand. If you placed sentence E at the end of the paragraph, you chose to end by introducing the particular study to be reported in the paper, also in keeping with the funnel or inverted pyramid pattern. The actual introduction is reproduced in Chapter 9, on page 247.

Notice in the original that the authors, David Graham and colleagues, begin as we've just described, using sentence D to announce the general topic or issue (peptic ulcer disease is chronic and recurs frequently), briefly elaborated with sentence C (which explains that antiulcer therapy can help but only

Effect of Treatment of *Helicobacter pylori* Infection on the Long-term Recurrrence of Gastric or Duodenal Ulcer

A. Recent studies have suggested that the eradication of *Helicobacter pylori* infection affects the natural history of duodenal ulcer disease such that the rate of recurrence decreases markedly (2–6).

B. In addition, studies of the effect of *H. pylori* eradication in patients with gastric ulcer have not been done.

C. The continuation of antiulcer therapy after ulcer healing results in a reduced rate of ulcer recurrence but does not affect the natural history of the disease, because the expected pattern of rapid recurrence resumes when maintenance therapy is discontinued (1).

D. Peptic ulcer disease is a chronic disease characterized by frequent recurrences.

E. We report the results of a randomized, controlled trial in which we evaluated the effect of therapy designed to eradicate *H. pylori* on the pattern of ulcer recurrence in patients with duodenal ulcer or gastric ulcer.

F. However, the interpretation of these results has been complicated by the fact that several of the larger studies did not use control groups or any form of blinding (3, 5, 6).

FIGURE 4.2 Scrambled introduction to Graham et al. (1992), from *Annals of Internal Medicine*, p 705.

temporarily, so does not affect the natural history of the disease). They then explain, in sentence A, that one approach *has* been shown to affect the natural history of the disease: eradicating the *H. pylori* infection. But this promising observation is qualified in sentences F and B, in which Graham et al. point out weaknesses in the research supporting this approach and also the absence of research investigating effects of this treatment on an important category of peptic ulcer (gastric). At this point, the discussion leads us to expect a response or solution to these problems, which is exactly what the authors then provide. In the final sentence, E, Graham et al. tell us they will report results of a study that has included control conditions (lacking in previous research) and that examines both types of peptic ulcer, gastric as well as duodenal. In this brief introductory paragraph, the authors have identified a research area, described the state of the field's knowledge in this area, and have shown how their study will advance that knowledge.

In asking you to try the "scrambled intro" exercise, we have borrowed an instructional technique from John Swales, a linguist who has studied the logic and form of scientific papers (Swales 1984; 1990; 2004). In a study of introductions from 48 scientific papers published in three research fields, Swales (1984) discovered a remarkable degree of consistency across fields and journals. He found, as we did in the above analysis, that authors use introductions to demonstrate that their research responds to a need or a gap in the field's knowledge. Swales (1990) explains that the introduction to a research report is designed to create a space or a niche that the new research will fill. In describing this Create a Research Space (CARS) model, Swales identifies three interconnected moves commonly found in journal article introductions, which we have summarized in Figure 4.3.

Common Moves in Research Article Introductions

Move 1	Establish topic and significance ("establish a territory")
	By claiming that the topic is of central interest to the field *and/or*
	By making generalization(s) about the topic *and/or*
	By reviewing previous research
Move 2	Establish need for present research ("establish a niche")
	By indicating a gap in previous research *or*
	By raising a question about previous research *or*
	By proposing an extension of previous research
Move 3	Introduce the present research ("occupy the niche")
	By outlining the purpose and/or main features of the study (*obligatory*)
	By describing the findings or conclusions of the study (*optional*)
	By previewing the organization of the report (*optional*)

FIGURE 4.3 Based on Swales's (1990) Create a Research Space (CARS) model of research article introductions (p 141).

These three rhetorical moves can easily be seen even in Graham et al.'s brief introduction. (Take a minute to find them.) In Move 1, Graham et al. begin with generalizations about peptic ulcer disease and its treatment (sentences D, C, A), incorporating an overview of previous research. In Move 2 (sentences F and B), they raise questions about prior studies and point to a gap in the research: gastric ulcer has not been studied. And in Move 3 (sentence E) they describe the main features of their study (it uses a randomized, controlled design) and its purpose (to evaluate the effect of *H. pylori* treatment on ulcer recurrence). Notice that Moves 2 and 3 in particular are clearly signaled by the authors. Readers can't miss Move 2 in sentence F, which is signaled by the contrastive adverb *however.* Move 3 is also clearly signaled, in this case by the shift to first person active voice: "We report…"

As you continue to read research reports in your field and others, you will come across many variations on these moves and the strategies for accomplishing them. Though the sequence outlined in Figure 4.3 is quite common, sometimes the moves will be made in a different order or may overlap, and the listed strategies will occur in varying combinations. Such variations may reflect the nature of research in a particular disciplinary area. For example, Samraj (2002) found that research introductions in the applied field of conservation biology often point to gaps or problems in real-world conservation management practices, rather than gaps in prior research, to establish the need for a new study. In contrast, authors from the theoretical field of wildlife behavior more often justified their new work by emphasizing gaps in previous research. In another distinctive pattern, Swales (2004) notes that the Move 3 strategy of previewing the organization of the report is not very common in articles following the IMRAD form but is "close to obligatory" in fields that do not use the IMRAD convention, such as computer science, biostatistics, and economics (p 232). In the absence of the predictable IMRAD organization, such a preview serves a valuable function in helping readers anticipate the shape of the argument to come. (See the *Clinical Toxicology* article by Spiller et al. [2002] in Chapter 11 for an illustration of this strategy.) In sum, we find the CARS model quite useful in identifying the basic gestures authors tend to make in introductions, but it is important to understand these gestures as flexible rhetorical moves that authors (and disciplinary communities) may combine in diverse ways to achieve their rhetorical goals. Despite variations in length, organization, headings, and other text features, effective introductions in all fields include broadly similar moves because they share the same broad goal: the authors want to convince readers that the topic is important and that their work on the topic will advance the field's knowledge. Thus the introduction serves several functions: it orients the reader to the research topic, reviews the current state of knowledge in the field, and establishes the need for the new work.[6]

The effectiveness of this argument for the significance of the new research rests largely on the authors' description of what the field knows now, which not only helps establish the authors' credibility in the field but in so doing creates common ground with readers and a shared context for understanding the new work. In an analysis of journal articles at early and later stages in the development of chaos theory, Paul and Charney (1995) found that when scientist authors were unable to use the conventional method of establishing shared context through research citation (i.e., when the research field was in its infancy and no prior research existed), they went to great lengths to create context through alternate means, for example, by introducing shared exemplars requiring extended elaboration. Once a research record developed, the same authors easily adopted the conventional research citation pattern that Swales had observed. Paul and Charney aptly describe research citation as a "disciplinary shorthand" (p 427) for establishing shared context with other members of a research community. Conventional ways to summarize the state of knowledge in the field and to acknowledge the work of others are discussed at more length in Chapter 5.

EXERCISE 4.4

Choose one of the sample research articles in this text and examine its introduction closely (for example, Chiba et al. [2002] in Chapter 9, Burkholder et al. [2005] in Chapter 10, or Reynolds et al. [2007b] in Chapter 12). Mark off the three basic moves outlined in Figure 4.3, circling any clear signals included in the text, and identify the strategies used to accomplish each of these moves. Write a paragraph in which you describe these moves and strategies, i.e., the authors' basic line of reasoning.

[6] In fact, the structure of the introduction, in which the research gap or problem is made prominent, can be understood to create the psychological desire for a solution (see Olsen and Huckin 1991). As rhetorician Kenneth Burke puts it, "form is the creation of an appetite in the mind of the auditor, and the adequate satisfying of that appetite" (1968, p 31).

EXERCISE 4.5

Choose a published research report from a journal in your field. Type up a scrambled version of the introduction to this report, as in Figure 4.2. (If you choose a multiparagraph introduction, break it into "packets" or clusters of sentences rather than individual sentences.) In class, have two or three partners read and unscramble the introduction, with the goal of reassembling the original line of reasoning. Look for similarities and differences in these responses. Is there an easily recognizable pattern in this introduction? Look at some other research introductions in your field. How common is the pattern you've identified? Which moves and strategies are flexible and which seem to be obligatory?

4.5 Describing Methods

The second major component of the research report is a description of the methods and materials used in the research. The "materials and methods" section traditionally follows the introduction, though some journals have begun to move these details out of the main body of the article to the end of the paper, sometimes set in a reduced font size, and/or to place some or all methodological details in online supplements. Berkenkotter and Huckin (1995) speculated that the trend toward deemphasizing the methods section in some journals indicates that readers rely heavily on peer reviewers' assessment of methodological details, saving their own reading time for inspection of the study's results. Diminished attention to methods in the main argument may also reflect the maturation of a field or research area: as particular methods become more established and familiar, their description requires less and less detail (VandeKopple 1998). But as we observed in Chapter 2, this "shrinking" of the methods section in some journals coincides with a trend toward expanding research reports in other ways, as electronic publishing enables authors to embed links within the text and post supplementary materials online.

The location of the methods section and the amount of attention it receives will also vary according to its role in the research argument being presented. Burkholder et al.'s 2005 paper in *Proceedings of the National Academy of Sciences* (*PNAS*), reprinted in Chapter 10, reports on a comparison of two methods for detecting *Pfiesteria* toxicity and therefore features a prominent and extensive "Materials and Methods" section describing these techniques. In contrast, Reynolds et al.'s 2007 report of their analysis of the Kepler supernova remnant (Chapter 12) contains no distinct methods section. Methodological details (e.g., the timing and duration of Chandra observations and the subsequent analyses performed) are integrated into a section titled "Observations and Results," where this information provides critical context for the description of what was observed. Wherever methods are described in articles in your field, they constitute an important component of the overall argument of the research report, for they provide the framework within which the study's results and conclusions were generated.

The content and organization of the methods section will also vary according to the type of research to be described. This variation is illustrated in Figure 4.4 with a simple comparison of subheadings used by different authors to organize this section of their reports. Although the logic of the methods section is dictated by the logic of the research and therefore varies widely across fields, notice in Figure 4.4 that there are some basic organizational similarities. Methods descriptions begin by identifying the subjects of study, whether they are bacterial strains, forests, or human beings. It is conventional in many environmental science fields, for example, to include a separate "study area" section in which the ecosystem under study is identified and located and its distinctive features described (as in Example B). Papers reporting research involving human or animal subjects typically include a subsection labeled "subjects" or "patients" or "population characteristics" at the start of the methods section (Example A). Example C similarly begins by identifying the *Pfiesteria* strains that are the focus of study.

Once the subjects of study have been identified, the materials and procedures used to study them can be described. Subheadings are often used to subdivide the methods section to highlight the various types of analyses that were performed, as in Examples A and C. It is often helpful and sometimes essential to use graphics in describing methods, such as maps of study sites or diagrams of experimental

Example A, from Chiba et al. (2002), *British Medical Journal* (reprinted in Chapter 9)
- Methods
  - Selection of patients
  - Randomisation and interventions
  - Adherence to drugs
  - Outcome measures (6 subsections)
  - Determination of sample size
  - Statistical evaluation

Example B, from Lorimer et al. (1994), *Journal of Ecology*
- Study areas
- Methods
  - Experimental design
  - Plot measurements and analysis

Example C, from Burkholder et al. (2005), *PNAS* (reprinted in Chapter 10)
- Materials and Methods
  - Dinoflagellate Cultures and SFBs with Juvenile Fish
  - Microbial Communities
  - FMS with Larval Fish
  - Tests for *Pfiesteria* Culture Purity
  - Toxicity, Toxin Production, and Environmental Relevance

FIGURE 4.4 Subheadings from the methods sections of selected journal articles.

apparatus. In Section 4.6 we will present some guidelines for incorporating graphics into your text.

As noted earlier, the concrete information in the methods section is usually presented in simple past tense, either active voice ("We *collected* water samples every three days") or passive ("Water samples *were collected*..."). Although the "scientific passive" has a long and venerable tradition, it is often easier and more direct to write in active voice, which is the mode preferred by many journal editors in the interests of brevity and clarity. The editors of the *Journal of Heredity,* for example, directly inform contributors that "first-person active voice is preferable to the impersonal passive voice" (*Heredity* 2008).

On the other hand, it is observed in the American Institute of Physics *Style Manual* (AIP 1990) that "the passive is often the most natural way to give prominence to the essential facts" (p 14). The AIP editors offer as illustration the sentence "Air was admitted to the chamber," in which it is not important to know who turned the valve (p 14–15). In an analysis of research articles in the field of speech-language pathology, Riley (1991) found passive voice to be substantially more common in methods sections than in other parts of the reports, though all sections contained a mix of passive and active verbs. The AIP recommends shifting to active voice where necessary to avoid confusion or awkwardness. You'll notice that active voice often leads naturally to the use of first person ("We collected..."), which is increasingly common in scientific prose, a trend also endorsed by the AIP (p 14) and other editorial panels.

Although it is generally recognized that the methods section cannot describe every action of the experimenters, the description should be detailed and complete enough to enable knowledgeable colleagues to repeat the experiment, observation, or calculations successfully. Standard procedures that will be familiar to your in-field readers can be identified quickly without citations or further explanation. Procedures established in previous studies typically appear with citations acknowledging the precedent. And new procedures or substantial modifications will be explained and justified. Just as the introduction section argues that the study was needed, the methods section argues that the study was sensibly designed and carefully conducted. This is the occasion to defend the decisions you made in designing and carrying out the research. Often these explanations are simply offered in passing, as in, "We increased the volume to 30 ml for the copepod *to minimize containment effects.*" At other times, an explicit justification is offered to explain a methodological choice: "The dinoflagellate's TFVCs require an unidentified substance in fresh fish excreta; *hence, it was necessary to maintain cultures using live fish.*"[7] Methods are sometimes described without such justification in student lab reports (because the primary audience, the instructor, has chosen the methods and does not need to be convinced of their validity), but in most other scientific contexts you will be describing methods *you* have chosen to readers who were not privy to your methodological decision making. How you explain and justify these choices is crucial to your *ethos* as a professional scientist.

[7]Both examples are from Mallin et al. (1995), emphasis added.

The degree of justification needed for a procedure depends on the status of these procedures in the research community. We noted earlier that this status may well change over time as a research area matures. For example, in an analysis of *Physical Review* articles reporting research in spectroscopy over the course of the last century, VandeKopple (1998) found that authors publishing as the field first emerged in the 1890s included many more experimental details than authors reporting similar types of work in the 1980s. The early researchers also tended to adopt a more cautious tone in describing their instruments and materials, taking care to depict their methods "as applying to one particular time and place, rather than... as firmly established and widely generalizable" (p 190).

In sum, the methods section establishes the conditions under which the results of the study were generated, and therefore the context in which they must be interpreted. In this sense, the methods "frame" the results (and represent a frame within a frame). Notice that describing the methodological details of an experimental study is comparable to the articulation of assumptions required in theoretical papers. In describing their methods, researchers articulate the assumptions they made about the phenomenon under study: for example, that it will or will not vary over time or as a function of temperature or nutrient content or medical treatment or altitude or other factor; that the effects of these variables are observable with these instruments or observational techniques; that these techniques are reasonably free of bias; that these subjects are representative of the larger population to which the researchers wish to generalize; and so forth. The validity of the study design rests on the persuasiveness of the researchers' description of the methodological decisions they made.

XERCISE 4.6

Look for instances of active and passive voice in one or more of the research reports in Chapters 9–13 or in sample articles from your field. Compare the types of information that tend to be presented in each mode. Do you perceive any patterns or strategies in the use of active and passive voice in different sections of these reports, or in articles from different research areas? (For example, how do your findings compare to the trend Riley [1991] observed in articles from the field of speech-language pathology [described above]?)

XERCISE 4.7

In the article by Burkholder et al. (2005), reprinted in Chapter 10, look for examples of each of the three levels of procedural explanation described above: (1) standard or routine procedures, (2) procedures established in previous studies, and (3) new procedures or substantial modifications. How much explanation or justification is provided in each case? Why?

EXERCISE 4.8

Turn the methods section from one of your recent class lab reports into a methods section suitable for a journal audience in your field.[8] Where appropriate, state the rationale for your methodological choices. Target a specific journal, and use informative subheadings if editorial guidelines permit.

4.6 Reporting Results

The presentation of results plays a critical role in the developing argument of the research report, for it is here that new evidence is presented to address the gap or question outlined in the introduction. At first glance, the content of this section of the IMRAD form seems obvious: this is where the data are presented. But presenting data is not a simple matter. Even if a journal offers the option of posting supplemental material online, researchers cannot display all the information accumulated during the study, which may consist of pages and pages of lab data or field notes in print or digital form. Journals do not allow room to report each day's striped bass capture rate in a three-month study period, for example, or pH levels from all soil samples in a 200-sample design—nor would readers want to spend the time to read these raw data.

Instead, the data are summarized. The first step is to *reduce* the data to a manageable size for presentation; in experimental studies this is often accomplished by converting raw data to means (averages) and by using figures and tables to represent the data visually. Mean capture rates might be reported for each week or month, depending on how much variation was observed over those time periods; the results of soil tests might be grouped and averaged according to the location of the samples or the distance from a waste discharge point. Once the data have been reduced in these ways, comparisons can be made; for example, changes in capture rate can be examined over time, pH levels at different sampling sites can be compared. It is these observed changes or differences (or the lack of change or difference) that constitute the answers to a study's research questions.

Reducing the data thus enables authors to take a second step in presenting results, that of *generalizing* from the data. Researchers want to point out the trends they've noticed so their readers can see why they drew the conclusions they did. If they are to convince readers that their conclusions are valid, they must first ensure that the patterns they saw in the data are readily apparent. Olsen and Huckin (1991) point out that both levels of information must therefore be presented: "(1) the major generalization(s) you are making about your data and (2), in compact form, the data supporting the generalization(s)" (p 363).

[8]We are indebted to Olsen and Huckin (1991) for this exercise.

Compare the following sentences, both of which refer to the data contained in a table:

Example A

Fifty percent of the eradication group and 36% of the placebo group responded successfully to treatment in the intention-to-treat analysis (table 2). In the all-evaluable-patients analyses, 54% of the eradication group and 40% of the placebo group responded favorably.

Example B

The proportion of patients who were considered a treatment success was significantly greater for the eradication arm than for the placebo arm, with comparable results in the intention to treat and all evaluable patients analyses (table 2).

Example B is from the report by Chiba et al. (2002), reprinted on pages 251–257. Example A is invented. If you look at Table 2 in the Chiba report, you'll see that Example A simply repeats data that can easily be read in the table itself. Example B, on the other hand, generalizes from the data, emphasizing the difference between the eradication and placebo groups and the similarity between the trends observed in the two types of analyses. Such generalizations are often stated in topic sentences at the beginning of paragraphs, as in Example B.

The relationship between data and generalizations is easily demonstrated by looking at how tables and figures are referred to in well-written reports. Tables, graphs, and other visual representations are essential tools for reporting scientific results, but it is important to keep in mind that graphics only present the data; the generalizations needed to interpret those data must be provided in the text. We recommend two essential steps in integrating visual and verbal information:

- Refer readers to the visual explicitly.
- Tell them what patterns to notice.

In Example B, the researchers refer readers to Table 2 by referencing it in parentheses at the end of the first statement describing data in that table. Other references to tables and figures are even more explicit, as in the following example, also from Chiba et al.:

Example C

Table 3 shows the impact of eradication treatment on disease specific measures of quality of life. The difference in the change in scores from pretreatment to study end showed significantly greater improvement in three of the five domains for the eradication arm.

The first sentence points readers to the table, identifying the kind of information to be found there (turn to Table 3 on page 254). The authors then go on to highlight the trends to be noticed in this table, helping readers interpret the mean differences listed in the second column by calling attention to the significance levels (P values) reported in the fourth column. (Three of the five P values fall below the commonly accepted probability threshold of 0.05, indicating that these differences are unlikely to have occurred by chance and are therefore considered "real" or significant differences.) As in Example B, the authors of the excerpt in Example C do not simply repeat data from the table in the text itself; rather, they use the text to summarize and characterize the data, to help readers see what they see in this set of numbers.

In Chapter 2 we discussed the critical role that visuals play in modern scientific argument, a role that has dramatically increased over time (Swales 2004; Gross et al. 2002). In an historical comparison of articles from prominent research journals in a range of fields, Gross et al. (2002) found that 88 percent of articles in their 20th-century sample included figures or tables, compared to 48 percent of articles published in the 19th century. On average, 26 percent of the "surface area" in the sampled articles consisted of tables and figures (p 200), a clear indication of the importance of visual evidence in this genre. Digital technologies have enhanced the range of visual options, with each type of visual serving a specific purpose in the research argument.

Tables are particularly useful for summarizing data when the exact values of the data are important or when there are no clear patterns that would lend themselves to graphical presentation (Monroe et al. 1977). Tables are the least "visual" of visuals insofar as they don't actually transform data into a pictorial form; however, the spatial arrangement of columns and rows enables researchers to display and categorize information, facilitating comparisons between groups or study sites or along other dimensions. Tables may be used to organize verbal as well as numerical data. In the paper by Spiller et al. (2002), reprinted in Chapter 11 (see page 334), Table 1 presents verbal data in two columns to facilitate comparison: a list of characteristic behaviors of the Delphic priestesses from the historical record is compared with a list of effects of ethylene inhalation documented in 20th-century science. In another paper from this study, De Boer et al. (2001) use tables to present and compare numerical data: hydrocarbon gas concentrations at different study locations (see Tables 1 and 2, reprinted on page 328).

Other types of visuals are better able to highlight continuous trends and patterns. For example, line graphs illustrate chronological trends well, for lines as a visual form naturally illustrate movement and direction over time. Line graphs are included in the papers by Graham et al. (1992) in Chapter 9 (page 248), and Burkholder et al. (1992) in Chapter 10 (page 269). You'll notice in both that the line graph's *x*-axis represents time, measured in units such as weeks or days.

Compare these *x*-axes with the *x*-axis in the bar graph Burkholder and Rublee (1994) included in their proposal in Chapter 10 (Figure 5, page 300). In this bar graph, eight sampling sites—four control sites and four discharge sites—are arrayed along the *x*-axis. Each bar represents one observation (the number of zoospores counted at the site), rather than a sequence of observations over time. The bar graph enables readers to see at a glance the relative magnitude of the counts at each site. The bar graph presents data in discrete categories, much like a table, but the visual depiction dramatizes the comparisons: similarities among control sites and among the discharge sites are easily apparent, as is the striking difference between the two conditions.

Graphs are labeled as *figures* in most scientific texts. Other types of figures include diagrams, cross-sections, maps, flowcharts, and various types of photographs, each of which serves a distinctive purpose and reflects the logic of the research design. For example, diagrams are useful for highlighting structural features and relationships (Olsen and Huckin 1991), as in Burkholder and Rublee's Figure 2 (page 290), in which the authors illustrate the many life stages of the toxic dinoflagellate, the relationships among these stages in the life cycle, and interactions with other factors in the environment (finfish and phosphates). De Boer et al. (2001) use three different types of line-drawn maps to show Delphi's proximity to two geologic faults (Figures 1, 2, 3; pages 326–327). In this article the maps function to locate the study site as well as to diagram the finding of the underlying faults, thus serving as support for both the methods and results of the study. As this example illustrates, though visuals tend to be concentrated in results sections, they may serve important functions in other parts of the research report as well.

Photographs and similar media are useful when observational detail of the object is important: Warren and Marshall use electron micrographs in their 1983 *Lancet* letters to show the shape and location of the *Campylobacter* bacteria they discovered (page 232); Chambers et al. (2007) present Landsat satellite images that they used to demonstrate changes in biomass along the Louisiana–Mississippi state line after Hurricane Katrina (page 381); and Reynolds et al. (2007b) merged three different types of X-ray images from the Chandra observatory to create a striking image of the Kepler remnant that enabled analysis of this supernova's origins. In these last two cases in particular, the visual images quickly came to represent the findings and were widely circulated. The Kepler image was featured as NASA's "Astronomy Picture of the Day," a research announcement of sorts that consists of little more than the visual itself (http://antwrp.gsfc.nasa.gov/apod/ap070116.html). Color is a significant feature of both the Kepler and the Katrina images that we are unfortunately unable to reproduce in the reprints in this text. If you access these articles (or the surrounding press coverage) online, you will see that color plays an important informational role in these images. In the Kepler visual, images from low-, medium-, and high-energy X-rays are represented in red, green, and blue respectively. Chambers et al.'s Landsat photos use a spectrum of colors to indicate the extent of biomass disturbance in locations that experienced different storm intensities. Both types of visuals are characteristic of their fields. (Chambers's use of before-and-after satellite imagery to study deforestation was a novel application of a method developed to study logging in the Amazon River basin [Kaufman 2007].)

As you examine research arguments in your own field, notice what types of nonverbal representations have become conventional. In addition to the types of visuals we've sampled here, consider other forms of modeling or numerical representation. For example, papers in organic chemistry rely heavily on diagrams of molecular models, whereas modeling studies in physics often include mathematical equations and formulae. Advances in digital technologies have considerably eased the challenge of incorporating visual and mathematical evidence into a research argument, and you will want to familiarize yourself with the technologies that your field relies upon.

Guidelines for designing figures and tables can be found in style manuals such as the CSE manual for authors (2006), in writing guides and textbooks (M. Katz 2006; Pechenik 2007; Day and Gastel 2006), and in the instructions to authors published by individual journals, particularly in fields that rely heavily on specialized types of visuals. For example, the journal *Poultry Science* provides guidelines for authors preparing tables, line art, grayscale (black and white) figures, color figures, and

photomicrographs (*Poultry Science* 2008). These varied sources all agree on the following general guidelines for preparing visuals:

- Each table or figure must be independent, that is, self-explanatory. Readers should be able to understand what kind of information is presented in the table without having to find the description in the text.
- For this reason, table titles (which appear *above* the table) should be as informative as possible: not "Table 1. Results" or "Table 1. Toxic Activity," but "Table 1. Toxic activity of purified *Pf*Tx extract from filtrate of *Pfiesteria* isolates in FMAs with larval C. *variegatus*, and cytoxicity to mammalian cells" (Burkholder et al. 2005; see page 309). Titles should identify the variables being compared in the table. All labels in the table (column headings, row headings, notes, etc.) should be clear and brief.
- Similarly, figure captions (which appear *below* the figure) should be as informative as possible: not "Figure 2. Ejecta spectra" but "Figure 2. Spectra of three outer knots shown in Fig. 1. ..." [followed by descriptions of the color and location of each knot's spectrum in the figure] (Reynolds et al. 2007b; see page 373 for the full caption). Symbols should be clearly identified in the caption or in a key; axes on graphs should be clearly labeled.
- Despite their independent status, figures and tables must also be *inter*dependent with the text. The visual and verbal presentations of results must work together. Visuals should be clearly referred to in the text, as discussed above, and they should appear in the text as close to the textual reference as possible.

Keep in mind that even though graphics are intended to be self-explanatory, readers will not know what *you* find interesting or noteworthy in the table or figure unless you tell them. Whether your data are presented graphically or discursively, that is, visually or verbally, be sure to highlight the trends you see and explain what they are based on.

It is conventional in many fields to subdivide the results section to highlight the different types of analyses reported, as in Burkholder et al.'s 2005 methodological comparison (Chapter 10) and Chiba et al's 2002 clinical study (Chapter 9). As these two papers illustrate, if subheadings are used in both the methods and results sections in an article, they typically include roughly parallel categories. Burkholder et al. organize both sections by detection technique (growth of microbial communities, SFBs (standardized fish bioassays), FMAs (fish microassays), toxicity); Chiba et al. subdivide both sections according to the various outcome measures they used (eradication of *H.pylori*, quality of life assessments, cost of health resources utilized). In sum, though researchers present their formal conclusions in later sections of the report, a great deal of interpretation goes on in results sections as well (Thompson 1993; Swales 2004). Summarizing, reducing, and generalizing from the data are all highly interpretive processes. It should be clear by now that researchers do not let the data speak for themselves; in summarizing their results, they also interpret them for the reader. They must present their data clearly, in the text and in any accompanying tables and figures, to demonstrate to readers that their interpretations are warranted.

EXERCISE 4.9

Read the introduction and methods sections (only) of the study by Graham et al. (1992) reprinted in Chapter 9 (pages 247–250).

1. Before reading the results section, study Table 1 in this paper. What trends do you see in these data? Draft a few sentences describing the patterns in this table as though you were writing up these results.
2. Then study Figure 1 in the same paper, and again draft some sentences about the patterns in the data. How would you describe the results presented in this figure?
3. Compare your descriptions with the authors' descriptions of this table and figure.

EXERCISE 4.10

Look for explicit references to figures and tables in sample articles in this text and from journals in your field.

1. Notice that the parenthetical reference to Table 2 in Example B on page 106 is different from the direct reference to Table 3 in Example C. How common are these two "reporting formulae" in the articles you examined? Do these forms vary across fields? Across journals? Pay special attention to the ways in which authors in your field refer to figures and tables.
2. Find 5 to 10 sample parenthetical references to figures and rewrite them as direct references. You may find that you develop a formula of your own for transforming these structures.
3. Describe how the raw data have been transformed in the figures or tables you have found; that is, how have the raw data been reduced into a summary visual form?

EXERCISE 4.11

Go back to the sample articles you examined in Exercise 4.10. List the types of graphics used in these articles, the kinds of data contained in them, and the patterns revealed. What claim in the text does each visual support? Why were these visual forms selected, and not others? Pay special attention to the purpose of the visuals and the information contained in table titles and figure captions.

4.7 Discussing Trends and Implications

As noted earlier, the discussion section of the IMRAD form completes the frame opened in the introduction by returning to the significance argument. The purposes of introduction and discussion sections are inversely related. Whereas the introduction introduces the research question and reviews the state of knowledge in the field that motivated the question, the discussion explains how the question has been answered (at least in part) by the new research and shows how the field's knowledge is changed with the addition of this new knowledge. Thus, the discussion describes a new state of knowledge in the field, one that in turn motivates further research questions, which are typically highlighted in this final section.

Structurally, the introduction and discussion are mirror images as well. Berkenkotter and Huckin (1995) describe the introduction as proceeding "from outside in" in that it begins by talking about the general topic and reviewing the existing research in the field, and then it narrows to focus on the particular work at hand. Conversely, the discussion proceeds "from inside out" by first summarizing major trends in the new results and then situating those results in the context of the field (p 41).

The new results are situated by comparing them with findings of previous studies and with the field's general understanding of the phenomenon under study. This is where the researchers offer their interpretation of their findings. They discuss how the new results extend, refine, or challenge previous findings or assumptions (Olsen and Huckin 1991). As the editors of the *British Medical Journal* (BMJ 2008) explain, a given study may have

> asked and answered a new question (one whose relevance has only recently become clear); contradicted a belief, dogma, or previous evidence; provided a new perspective on something that is already known in general; [or] provided evidence of higher methodological quality for a message which is already known.
> (http://resources.bmj.com/bmj/authors/types-of-article/research)

The discussion of implications must be clearly tied to the current results and must demonstrate an awareness of the limits of those results. In sum, the discussion section is the place to

- Briefly summarize the major findings, including the magnitude and direction of the effects observed (compared with what others found or compared with what was predicted or might be expected).
- Acknowledge the advantages and limitations of the methods used in the research (and comment on how these features may have influenced the observed effects).
- Explain the implications of the findings for current practice, policy, or theory.
- Outline the research questions that remain.

Notice that these discussion issues are interdependent. In commenting on the magnitude and implications of the new findings and the research questions that remain, it is important that the researchers recognize and acknowledge the limitations of their study. Scientists must anticipate the questions other researchers might have about their methods, findings, and conclusions, and must answer these questions in the text before they are asked. It must be clear to readers that the authors have considered "rival hypotheses," that is, possible alternative explanations for their findings. Philosopher Stephen Toulmin, an expert on scientific argumentation, calls these answers to potential questions, objections, and counterarguments "rebuttals" (Toulmin et al. 1984). According to Toulmin, rebuttals are the recognition of the circumstances or exceptions that might undermine the argument of the research.

Rebuttals often consist of further qualifications or acknowledgments of limitations, exceptions, and the need for further study and research. Rebuttals therefore are a way for a writer to verbally close loopholes, seal leaks, and tie up loose ends in the logic of the report. This sentence from the third paragraph of the discussion section in Graham et al. (1992) is a good example (see page 250):

> Although some may argue that the lack of double-blinding introduced an important bias into our study, no objective data support such a contention, and we believe such a scenario extremely unlikely, especially considering the equipment now available for studying gastroduodenal mucosa.

All arguments, of course, are open to rebuttal; as we discussed in Chapter 1, scientific statements must be falsifiable to be accepted as valid. But in anticipating objections and answering them, scientists show they understand the limitations of their research, the nature of research problems in their field, and the expectations of their colleagues. Thus, the professional use of rebuttals is another way scientists enhance the credibility of their research as well as their *ethos* as researchers.

As is the case in other sections of the report, the emphasis in discussion sections varies somewhat across fields. It is conventional in journals in applied fields, such as the *Journal of Wildlife Management*, to include a separate section on management implications after the main discussion. Similarly, discussion sections in agricultural journals may include advice for producers on feeding practices or litter composition. Contributors to medical journals may offer recommendations for clinicians and/or for public health policy (see the Chiba et al. paper in Chapter 9 for an example). In these and other applied areas, the discussion section is the place for researchers to show how their results pertain to actual practice or policy in the field.

In basic research areas the focus is not on practical applications but on the theoretical or methodological implications of the new results. In their report of the Kepler SNR discovery, for example, Reynolds et al. (2007b) explore the implications of their analyses for the field's understanding of supernovas and of the circumstellar medium (CSM), pointing out that this new information will also enable the field to test alternative models of the nature of the CSM (pages 372–375). The "Discussion" section in Burkholder et al.'s methodological study (pages 307–312) also explores the implications of their results for the field's theoretical understanding, in this case of toxic *Pfiesteria*, but their primary goal is to explore the methodological implications of their results. The study aimed to

resolve conflicting reports in the field about *Pfiesteria*'s toxicity by comparing methods used in studies with conflicting conclusions. The "Discussion" section highlights their conclusion that choice of method is critical in explaining this variation and thus an essential consideration for further research: "As shown by comparison of this study with refs. 21–23 and 25, recognition of variability in toxicity expression and other traits among strains (6), use of culture conditions conducive to toxicity expression (5, 10, 11), and appropriate assays for toxin will remain critical in forming sound insights about toxicity of harmful algal species and genera" (Burkholder et al. 2005; see page 312).

Thus, discussion and conclusions sections, whether combined or labeled individually, represent the conclusion to the broader argument of the research report. Research authors do not leave it up to readers to draw conclusions about the data. They tell readers *their* conclusions, the ones the researchers believe the data support, and they provide enough information about the data and the conditions under which the data were generated to enable readers to determine whether their conclusions are justified. The American Institute of Physics (AIP 1990) describes conclusions as "convictions based on evidence" (p 4). The discussion section is the place to state your convictions and demonstrate how they follow from the evidence you present in other sections of the report.

We have focused thus far on the logic and structure of the arguments presented in research reports, but it is also important to notice distinctive features of the language in which these arguments are expressed. The persuasive and interpretive nature of scientific texts can be detected even in the language of individual sentences if we look carefully at how scientists phrase their claims and conclusions.

In a study of scientific claims, Penrose and Fennell (1993) asked experienced scientists from a variety of fields to complete sentences like the following[9]:

> These data ______________ that the minimal response rate of interest should be .15.
>
> Results of this study ______________ that significant genetic divergence has occurred among geographically separated groups of raccoons.

The verbs *suggest*, *indicate*, *show*, and *demonstrate* were the most common responses from these experts, regardless of field. The finding that responses from these individuals were fairly uniform indicates that these terms are conventional across disciplines and are not unique to writing in, say, geology or botany. Notice that we've used one of these conventional verbs, *indicates*, in the preceding sentence to signal our interpretation of Penrose and Fennell's results. The sentence tells you that from the responses of these individual scientists we are generalizing about scientific discourse at large.

When we say that verbs like *suggest* and *indicate* are "conventional" in scientific discourse, we mean that they are commonly used constructions that carry particular, agreed-upon meanings in the community. These conventions enable scientists to make claims within the established parameters of

[9] Sentences from Sylvester (1988, p 833) and Hamilton and Kennedy (1987, p 270).

knowledge-making in science. That is, these expressions enable a researcher to put forth a conclusion—to contribute to the advancement of knowledge in the field—while at the same time acknowledging that it *is* a conclusion—an interpretation of the facts and not a fact itself. Use of these tentative or hedging verbs signals to other scientist readers that this author is aware of the interpretive nature of scientific knowledge and that the claim is to be interpreted as "true" only within the boundaries of current knowledge and conditions (Hyland 1996; Gross et al. 2002). In examining research texts in psychology, Madigan et al. (1995) observed that hedged conclusions may be more convincing than more strongly worded claims because they convey "proper respect for the empirical process" (p 432). In addition to enhancing author credibility, there is some evidence to suggest that the inclusion of appropriate hedges helps readers comprehend the text (Crismore and VandeKopple 1988).

Scientists also use other kinds of hedges or qualifiers to convey the interpretive nature of their claims. Adverbs and adverbial phrases are often used to note limitations or special conditions; examples include *possibly, probably, very likely, necessarily, certainly, without doubt, presumably, in all probability, hypothetically, maybe, so far as the evidence suggests*, and *as far as we can determine* (Toulmin et al. 1984). Such qualifiers indicate the strength or extent of the claim being made, as in the following examples from the start of the "Discussion and Conclusions" section of the 2007 Reynolds et al. report (emphasis ours):

> We believe that X-ray and optical evidence points *compellingly* to the conclusion that Kepler resulted from a thermonuclear event.
>
> However, our deep Chandra observations also confirm that Kepler's blast wave is encountering material with at least solar metallicity, coincident with optically emitting N-enhanced material—*most likely* circumstellar material lost by a fairly massive star . . .

In addition to verbs and adverbs, a third type of qualifier is the modal auxiliary verb (Toulmin et al. 1984). Verbs like *may, might, would, could, should, must, can*, and *shall* are used to indicate qualifying conditions, as in the following examples:

> Given its broad temperature and salinity tolerance, and its stimulation by phosphate enrichment, this toxic phytoplankter *may* be a widespread but undetected source of fish mortality in nutrient-enriched estuaries. (Burkholder et al. 1992)
>
> The stomach *must* not be viewed as a sterile organ with no permanent flora. (Warren and Marshall 1983)

Hedging verbs, adverbs, and modal auxiliary verbs can and do occur anywhere in a scientific text where researchers need to qualify or limit their claims.[10] In a sense, then, qualifiers are related to rebuttals insofar as scientists use them to acknowledge the limitations of their work and to anticipate and head off questions and counterarguments that readers might pose. These linguistic devices thus reflect the interpretive and interactive nature of knowledge-building in

[10]See Hyland (1996) for a detailed analysis of these and other forms of hedging.

science. As you join the community of scientists, you are acquiring knowledge of both the logic of scientific arguments and the language in which that logic is expressed.

EXERCISE 4.12

The Graham et al. (1992) report contains several rebuttals in the last two paragraphs of the discussion, leading up to the final recommendation supporting Marshall's ulcer therapy (see page 250). What rebuttals have the authors included? What counterarguments are these rebuttals to? Why do you think the authors felt they had to include these rebuttals in their report? It may be useful to know that Graham was a former opponent of Marshall's treatment.

EXERCISE 4.13

1. Analyze the discussion and conclusion sections of three or more full-length research reports from journals in your field (include any separate sections describing recommendations or management implications). List the types of discussion issues raised in these sections. Use the categories listed in this section as a guide (summary of results; advantages and limitations of methods; implications for practice, policy, or theory; remaining questions), but be prepared to expand the list or create subcategories as necessary to best describe the kinds of issues raised in your field.
2. In groups of three or four students from different fields, compare lists and prepare to discuss similarities and differences across these research areas. How do these similarities and differences reflect the nature of research in these fields?

EXERCISE 4.14

1. In the "fill-in-the-blank" study mentioned above, Penrose and Fennell (1993) found that first-year students and non-science majors were more likely to supply the word *prove* in these sentences than were science majors or expert scientists. Why is this usage less conventional among scientists? What is the difference between *suggest* and *prove* in these types of scientific claims?
2. Another unconventional choice some students made in this study was to use words like *conclude* or *hypothesize* in the sample sentences. What is unconventional about these choices? How does *conclude* differ from *suggest* or *indicate* in the context of these sentences? How might you revise these sentences to make *conclude* an acceptable option?

EXERCISE 4.15

Examine the discussion and conclusions section(s) of a research report from your field or one of the sample articles in this text, for example, Chiba et al. (2002) in Chapter 9, or Etiope et al. (2006) in Chapter 11. Look for instances of hedging in the text, particularly the three categories of qualifiers described above: verbs, adverbs, and modal auxiliary verbs. Look for other hedging devices as well. Would you propose any additional categories? What purposes do the hedges serve? How common are they in the sample articles you've chosen? Compare your findings with those of students examining other fields. Do you see any differences across fields in the use of hedges?

EXERCISE 4.16

The original title of the Burkholder team's letter to *Nature* (1992) was "New 'phantom' dinoflagellate is implicated as the causative agent of major estuarine fish kills." This title was shortened during the publication process (see page 268), much to Dr. Burkholder's dismay. What is the effect of the title change, and why do you think Burkholder was dismayed?

4.8 The Research Report Abstract

The abstract is a summary of a document's major points, typically appearing at the start of the journal article, and, as we saw in Chapter 2, accessible via online indexes and abstract databases. Along with the title of the report, the abstract helps readers decide whether the paper is pertinent to their research interests. The Council of Science Editors (CSE 2006) explains that "[b]ecause abstracts also appear in abstract journals and online databases, separated from the articles they describe, abstracts should be complete and understandable unto themselves, without reference to the full article" (p 460). The abstract therefore must represent the full argument contained in the report: the topic and purpose of the study, the methods used, the results obtained, and the conclusions drawn from those results. However, this argument must be outlined in extremely condensed form, usually only about 5 percent of the length of the full paper (AIP 1990).

Given its role in representing a larger document, the abstract can be described as a "contingent" genre: its content and form are contingent on the content and organizational logic of the document being abstracted. We will talk about research report abstracts in this chapter and will provide guidelines for the conference presentation abstract in Chapter 6 and the research proposal abstract in Chapter 7. Abstracts will vary considerably within these categories as well, however, reflecting variations in purpose and logic across research fields, journals, and articles. Some journals provide formal guidelines for the abstract that embody the standard research logic of their respective fields. *Annals of Internal Medicine*, for example, requires authors of research articles to follow a structured format for the abstract, as illustrated in the paper by Graham et al. (1992) in Chapter 9 (see page 247). This type of structure—in this case with separate sections for the study's objective, design, setting, participants, intervention, measurements, results, and conclusions[11]—is used in other journals reporting clinical trials as well. (See Chiba et al. [2002], on page 251, for an illustration of the *British Medical Journal*'s very similar form.)

Many journals, however, specify only a maximum length for the abstract (typically 150 to 250 words) and leave its structure up to the author. Because the abstract mimics the form and logic of the full report, the structure should be relatively straightforward. If the report follows the IMRAD form, the abstract is likely to include four basic moves representing the major parts of this pattern, and verb tense will shift accordingly (Olsen and Huckin 1991): the topic will be introduced in present tense, usually in a sentence or two; the background and/or need for the study will be outlined in another few sentences (but typically without references to prior studies [CSE 2006]); methods and results will be briefly described in past tense; and the major conclusions and implications of the study will be stated in present tense. Abstracts for IMRAD articles can be easily generated using this four-part structure. (See the Knutson et al. abstract in Chapter 13 for an example.)

If the report follows a logic other than the IMRAD pattern, however, the structure of the abstract will vary accordingly. For example, the abstract for Spiller et al.'s (2002) *Clinical Toxicology* paper defending the gaseous vent theory of the Delphic oracle (see page 330) begins with one sentence summarizing the historical claim that intoxicating gases inspired the oracle, followed by three sentences summarizing the geological and chemical evidence that supports this claim. The fifth and final sentence states the authors' conclusion that the priestess's trance was caused by ethylene inhalation. Thus, the abstract encapsulates the line of reasoning followed in this particular article.

The IMRAD and non-IMRAD samples mentioned above are all examples of *informative* abstracts, that is, abstracts that summarize the information in the larger text. This type is distinguished from the *descriptive* or *indicative* abstract often adopted for research reviews (Olsen and Huckin 1991; CSE 2006) and conference proposals. Indicative abstracts indicate what kinds of information will be contained in the paper, rather than providing a summary of that information. An example from the *Journal of Computational and Graphical Statistics* is presented in Figure 4.5. As this example illustrates, the descriptive approach is particularly appropriate when describing research involving mathematical procedures or models, which cannot be presented in condensed form. Rather than attempting to abbreviate these models, the authors in Figure 4.5 preview the basic steps or components of their model, telling readers what will be demonstrated in the paper. (Notice that this indicative approach previews the content of the paper in much

[11]The full *Annals* guidelines now also include an initial "background" section and a "limitations" section following results (http://www.annals.org/shared/author_info.html).

Calculation of Posterior Bounds Given Convex Sets of Prior Probability Measures and Likelihood Functions

Abstract

This article presents alternatives and improvements to Lavine's algorithm, currently the most popular method for calculation of posterior expectation bounds induced by sets of probability measures. First, methods from probabilistic logic and Walley's and White-Snow's algorithms are reviewed and compared to Lavine's algorithm. Second, the calculation of posterior bounds is reduced to a fractional programming problem. From the unifying perspective of fractional programming, Lavine's algorithm is derived from Dinkelbach's algorithm, and the White-Snow algorithm is shown to be similar to the Charnes-Cooper transformation. From this analysis, a novel algorithm for expectation bounds is derived. This algorithm provides a complete solution for the calculation of expectation bounds from priors and likelihood functions specified as convex sets of measures. This novel algorithm is then extended to handle the situation where several independent identically distributed measurements are available. Examples are analyzed through a software package that performs robust inferences and that is publicly available.

FIGURE 4.5 Sample descriptive abstract from the *Journal of Computational and Graphical Statistics* (Cozman 1999).

the same way as the previewing strategy that Swales found to be common in introductions to non-IMRAD articles [Figure 4.3].)

The indicative abstract is less appropriate for reports of experimental research, for this approach provides little information about the study itself or its results and is therefore less useful to readers (Olsen and Huckin 1983). For example, compare the following hypothetical indicative abstract with the informative abstract that accompanies Graham et al.'s (1992) paper in the *Annals of Internal Medicine*, contained in Chapter 9 (page 247):

> The purpose of this report is to determine the effect of treating *Helicobacter pylori* infection on the recurrence of gastric and duodenal ulcer disease. Results of a clinical study of recent ulcer patients under two treatments are reported.

Though this hypothetical abstract does provide a general outline of Graham's study, it withholds critical information that the clinical audience of this journal would be interested in, namely the types of treatment tested and the outcomes of the tests. Given the type of research being reported, the extended informative abstract that this journal requires is much better suited to its readers' needs.

EXERCISE 4.17

Read the abstracts for the papers by Burkholder et al. (2005) in Chapter 10 (pages 307–312) and De Boer et al. (2001) in Chapter 11 (pages 326–329). Identify each as an informative or an indicative abstract. Identify the major moves in the abstract and corresponding verb tense shifts.

EXERCISE 4.18

Write a 100- to 150-word informative abstract for the research report by Chambers et al. (2007), reprinted on page 381.

4.9 Brief Report Genres: Research Letters and Notes

In addition to the full-length research report, many journals publish brief reports in the form of *letters* or *notes*, an increasingly common set of genres designed to enable researchers to make quick announcements of important findings to the relevant scientific communities. The Burkholder team's original announcement of their *Pfiesteria* findings was presented as a research letter in *Nature*. According to *Nature*'s Guide to Authors (2008a), letters are "short reports of original research focused on an outstanding finding whose importance means that it will be of interest to scientists in other fields." Chambers et al.'s one-page report on Katrina's effect on Louisiana forests (Chapter 13) is an example of an even more abbreviated genre; it appeared in the "brevia" section of *Science*, another interdisciplinary journal that, like *Nature*, offers these briefer forms especially for findings of interest to scientists in a wide range of fields: "Interdisciplinary work, or experiments or analyses that produce a result of general interest, are especially appropriate for this section" (*Science* 2008). Other journals solicit similar types of articles. *Analytical Chemistry* (2007) publishes "Correspondence" ("brief disclosure[s] of new analytical concepts of unusual significance") and "Technical Notes" ("brief descriptions of novel apparatus or techniques"). The journal *Physical Review Letters* is devoted exclusively to "providing rapid publication of short reports of significant fundamental research in all fields of physics" (*PRL* 2008). Many of these genres have evolved from earlier, less formal forms: *Physical Review Letters* essentially began as a "Letters to the Editor" section in the journal *Physical Review* (Blakeslee 1994).

In most cases, research letters undergo an expedited review and publication process designed to enable researchers to communicate important findings as quickly as possible. The *Astrophysical Journal*, for example, publishes *Astrophysical Journal Letters* as Part 2 of the journal. The *Letters* is described as "a peer-reviewed express scientific journal" (*Astrophysical Journal Letters* 2008). *Letters* articles first appear on a Rapid Release website sponsored by the journal's publisher, University of Chicago Press. They then appear with a complete electronic issue of the journal and only later in a print version along with Part 1, which is published three times a month. Reynolds et al. announced their Kepler discovery in a 2007 letter in this journal (pages 372–375). Though limited to four pages in length, the letters are not governed by any special organizational constraints and may be similar in form to Part 1 articles, which may run up to 20 pages. Letters are distinguished from full articles primarily by their urgency—their rhetorical exigence. In addition to satisfying the evaluative criteria established for Part 1 articles, *Ap.J.* letters must meet two further requirements, timeliness and brevity, which the editors describe as follows:

> **Timeliness**—A Letter should have a significant impact on the research of a number of other investigators or be of special current interest in astrophysics. Permanent, long-range value is less essential. A Letter can be more speculative and less rigorous than an article for Part 1 but should meet the same high standard of quality.
>
> **Brevity**—A Letter must be concise and to the point and require no more than 4 journal pages.... Within this space limitation, sufficient introductory background material should be included, and the content of the paper should be such that it can be generally understood by scientists who are not specialists in the particular field. (http://www.journals.uchicago.edu/page/apjl/criteria.html)

Though the brief report category includes forms serving a variety of purposes, from presenting preliminary results, to introducing significant analytical concepts, to describing new techniques, research letters are typically used to present innovative research or to announce novel findings. Watson and Crick's 1953 letter to *Nature* on the double helix structure of DNA is a case in point, as is the Burkholder team's letter in the same prestigious journal. Marshall and Warren initially reported the presence of bacteria in the stomach in joint letters to the *Lancet* (Warren and Marshall 1983; see pages 231–233). Notice that neither the dinoflagellate, *P. piscicida*, nor the "ulcer-causing" bacterium, *H. pylori*, had yet been named at the time the Burkholder and the Marshall and Warren letters were published, indicative of the early stage at which these reports appeared. Both might be considered cases of "revolutionary" or extraordinary science (Toulmin et al. 1984; Kuhn 1996). That is, both research teams were reporting findings that, if further supported, could significantly alter basic knowledge paradigms in their respective fields: the Burkholder team described a new family, genus, and species of algae that evidenced predatory behavior and was found to be responsible for numerous previously unexplained fish kills; Marshall and Warren described a bacterium that not only was found to live in the supposedly sterile environment of the stomach but also was potentially linked to illnesses the field firmly believed to be caused by psychological rather than physical factors. In both cases, these early announcements were (and continue to be) followed by a wealth of further research in which these preliminary findings are tested and extended.

In contrast to full-length reports, which can run 3000–6000 words, research letters and notes are quite restricted, at least in their print versions. *Science* brevia can be no more than 800 words (including author names and references) and may include one figure or table. *Nature* limits letters to 1500 words and 30 references (contrasted with the 50 references allowed in full-length reports). Electronic publication has enabled both journals to expand these limits online, however, as authors are permitted to link supporting material to the online version of their articles. For example, Chambers et al. (2007) posted eight pages of Supporting Online Material for their *Science* brevia piece, including a three-page Materials and Methods section, two figures, a table, and four additional references. Consistent with the trend reported earlier toward deemphasizing methods in research

reports, both *Nature* and *Science* recommend moving some methods information into these supplements.

Notice that neither the Chambers nor the Burkholder letter uses subheadings, but both articles include all the standard components of the IMRAD format, albeit in much less elaborated form. As indicated in the *Astrophysical Journal*'s guidelines above, brief reports tend to follow the same logic and organization as full-length reports in a given research discipline. One interesting variation we've come across is in the abstract, an element that some journals have adjusted in keeping with the emphasis on brevity in the letter genre. *Nature* and its affiliated journals require a standard 150-word abstract for their full-length articles but have adopted a different convention for their shorter research letters. Letters are to include a 200-word summary paragraph at the start of the article in lieu of a conventional abstract. Though this paragraph is to include all the standard abstract components (background, rationale, main results, implications), it is to be "fully referenced" and should function as part of the main text, not as a separate element (*Nature* 2008a). The Knutson et al. letter abstract from *Nature Geoscience* in Chapter 13 is an example, as is the first paragraph of the Burkholder et al. *Nature* letter. This introductory paragraph is then also reproduced as the letter's abstract online, so it must include a preview of results and conclusions, elements that are usually optional in research report introductions (review Move 3 in Figure 4.3). *Nature* provides an annotated illustration of their requirements for this summary paragraph in their guide to authors: www.nature.com/nature/authors/gta/Letter_bold_para.doc.

In a study of the journal *Physical Review Letters*, Blakeslee (1994) points out that the brevity of these reports may make it difficult for reviewers to evaluate the quality of the science being reported, and indeed the letters forum allows little room for the types of evidence we expect to find in full-length research arguments. Nor does it allow for detailed explanations of unexpected findings or extensive rebuttals (as illustrated by the responses elicited by Fleischmann and Pons's letter [1989] in the *Journal of Electroanalytical Chemistry*, announcing the creation of cold fusion). The letters genre is well suited, however, for presenting quick reports of new developments and recent observations, as the letters by Warren and Marshall and by the Burkholder, Chambers, and Reynolds teams illustrate. Letters often have something of a journalistic flavor when compared with the more formal full-length research report, consistent with the broader audience of this genre and with the function of presenting "cutting-edge" research (Blakeslee 1994).

EXERCISE 4.19

Look for the basic IMRAD elements in the Burkholder team's letter to *Nature* (Chapter 10). In what ways does this short report follow the IMRAD pattern? In what ways does it deviate from this pattern? Where are the basic research report moves made (introducing the problem, describing methods, reporting results, drawing conclusions)? Notice that table and figure captions are quite long in this report. What kind of information is contained in table and figure captions, and why is it there?

4.10 How Scientists Write Reports

The order in which report sections are written is rarely the same as the order in which they appear in the finished text. Your abstract is the first thing readers will see, but you won't be able to write it until you've at least sketched out the main body of your text. Perhaps you'll sketch out your methods section first, while specific details and decisions are still fresh; or you may begin by constructing the tables and figures you will use to present your results, filling them in as the data are generated and analyzed (Monroe et al. 1977). As noted earlier, your graphics represent the logic of your research design; the form of your tables and figures is likely to be determined long before you begin to write. LabWrite (2004), an online guide to writing lab reports, suggests writing methods and results first and then moving on to the intro and discussion sections (http://www.ncsu.edu/labwrite/po/po-homepage.htm).

As is the case with many types of writing, the introduction to the research report is often revised throughout the drafting process; some authors even write it last. The focus and argument of the introduction depend in part on the outcome of the study. For example, a team of researchers may discover that their findings raise questions they did not expect to be important, and thus the study makes a somewhat different contribution to the field than they had anticipated. The introduction needs to prepare readers for this contribution so that it is recognized and appreciated as important. Even though the purpose and design of the study have not changed, the researchers will need to adjust their review of background issues and research to establish a context for later commenting on these new questions. In short, you may not be able to finalize your introduction until you've thought about the implications you want to raise in the discussion section.

Writing a report is thus a recursive process in which authors continuously revisit and rethink their earlier arguments in light of their results and further thinking. In a study of the composing processes of nine eminent biochemists, Rymer (1988) found they employed a wide range of writing strategies and styles. Some subjects reported that they typically spend a great deal of time planning and outlining before drafting sections of the text, whereas others begin by writing a full "impressionistic" draft of the whole paper, refining it in later stages of the process. Most scientists use a combination of these approaches, adjusting their processes according to the type of research they're reporting, their familiarity with the prior research and the target journal audience, the amount of time they have available, and so forth.

The number of authors involved in a project also influences the structure of the writing process. As we've discussed, collaborative projects are increasingly the norm in most scientific fields. The average number of authors per article in the *New England Journal of Medicine (NEJM)*, for example, increased from one in 1925 to about six in 1995 (NAS 1995, p 13), by which time *NEJM* had instituted a cap of 12 authors per article (Kassirer and Angell 1991). In July 2002, *NEJM*'s editors lifted the cap, allowing the number of authors to continue to increase. The editors explain that as medical research has advanced, "investigators with a broader range of skills than were required in the past are often needed to take new ideas from the bench to the bedside and to conduct large clinical trials" (Drazen and Curfman 2002). This trend in multiple authorship has been a matter of some debate in science and in academia at large, for it raises issues of professional ethics and responsibility, as we discussed in Chapter 3.

Research teams manage the writing process in a variety of ways. In some teams, one author drafts the entire paper and sends it around to others for their comments and revisions. In fact, this is a common teaching model. Blakeslee (2001) observed a physics research team in which a graduate student learned to write papers by taking responsibility for the team's initial drafts, revising multiple drafts in response to his adviser's feedback. In other working groups, different members of the team may draft different sections according to their role in the research; for example, those who carried out the procedures and collected the data will draft the methods and results sections pertaining to their parts of the project, while the project leader who initially conceptualized the study will write the initial draft of the introduction and discussion (Rymer 1988). As discussed in Chapter 2, new digital technologies facilitate collaboration across time and distance, but this "distanced" collaboration may place higher demands on authors' project management skills and interpersonal relations.

If you completed the interview assignment in Chapter 1, you no doubt discovered that scientists spend a great deal of time writing, revising, and polishing papers before submitting them for journal review. The physics team studied by Blakeslee (2001) generated 21 drafts of their paper over a five-month period. One of Rymer's biochemists described a "predrafting" stage lasting approximately three years, during which the study was conceived and carried out and the postdoctoral fellows on the project drafted figures and tables as well as the methods and results sections. Once the lab work and analysis were completed, the project leader drafted and revised the introduction and discussion sections over a period of two weeks and then spent another two months pulling the manuscript together, which included revising the methods and results sections provided by the postdocs and soliciting feedback on the draft from colleagues (Rymer 1988).

Clearly, the form of the final written product tells us little about the process through which that text came to be. Unlike the conventions of the written report, writing processes seem to be governed not by field-specific convention but by the habits, skills, and preferences of the individuals who make up the research team.

4.11 How Scientists Read Reports

It should be clear from this chapter that the written reports themselves *are* governed by the conventions of their respective research fields and by the conventional practices of journals within fields. You'll recall that "conventional" practices are those that are customary in a community and thus familiar to all members. Readers in a community use their knowledge of these conventions to facilitate the reading and interpretation of the written texts those conventions govern. Thus, readers familiar with the IMRAD form will know where to find the results in a report quickly, where to look for the authors' interpretations of the results, and so forth. They will not need to read a paper from start to finish in order to discover what kind of research was conducted and what was found.

In fact, although editors and reviewers may take the time to read a paper from start to finish, scientists reading for their own purposes are far less likely to do so (Burrough-Boenisch 1999). Few scientists have the time or the inclination to read journal articles in their entirety in the order in which they appear in print (Bazerman 1985; Berkenkotter and Huckin 1995). Readers rely heavily on the titles and abstracts of published reports, not only to help them decide whether to read the paper but also to help them quickly learn the key features of the study. They then can turn immediately to pertinent sections of the report for the information they are most interested in. From consultations with researchers in physics and biology, Berkenkotter and Huckin (1995) determined that readers typically began by scanning the title and abstract of an article and then looking for the data, focusing on the tables and graphs in which the data are summarized. Only after examining the data themselves did these scientists read the results section provided by the authors. The rest of the reading process was quite variable; readers selectively read or skimmed the introduction, methods, and discussion sections, depending on how much they already knew about the topic, the methodological approach used, and the results of prior studies, and depending on their familiarity with other work of the authors. In an earlier study of physicists, Bazerman (1985) found similar variation in reading strategies. On some occasions readers would read an article's introduction and conclusion to get a sense of the focus of the study for future reference, skipping over details of methods and results; but in other contexts, as when reading a paper on a very familiar topic, the same readers might invert this pattern, ignoring the contextual information in the introduction and conclusion and concentrating instead on methodological details, calculations, and results. As we've discussed, readers of online journals may need to follow links to supplemental materials if they are interested in full details of materials and methods or additional results, an option that current technologies make readily available. In this sense, digital technologies have given readers even more control over, and responsibility for, their navigation of a given text.

Given these varied reading strategies, we can see why section headings, figure captions, and clearly labeled links are important in research reports, and why the content of titles and abstracts is critical. The final form of the report may reflect neither the order in which it was written nor the order in which it will be read, but it must match the expectations of readers in the research community, who will expect to find particular kinds of information and particular parts of the overall argument under conventional labels in predictable locations. The basic form and logic of research reports has remained relatively consistent over the last century, despite the many developments in technological publication and modes of access (Mackenzie Owen 2005; Gross et al. 2002). The paper must reflect the logic of presentation with which readers in the field have become familiar.

It's important to keep in mind that readers have expectations about the logic within sections as well. Paul and Charney's (1995) observations of scientists reading articles on chaos theory indicated that their readers were generally familiar with the basic introduction moves described in Section 4.3 (though they may not be aware of this formula). When the authors had followed this pattern, these readers used this familiar structure to help them incorporate the new work into their current knowledge of the topic. In fact, the readers in this study—chaos researchers from the fields of physics, mathematics, ecology, engineering, and meteorology—all paid more attention to the context-setting information provided in the introduction than to the description of the new study itself. That is, the readers' first concern was "whether they could relate the reading to their prior knowledge and to their own work" (p 427). In short, readers expect to find these connections in the introduction, and authors must take care to provide them.

This discussion has implied that readers are active participants in the generation of knowledge through text. Scientists don't just gather facts when they read; they interpret those facts and carefully consider the interpretations proposed by the authors. They pay attention to how the authors designed and conducted the study, the conditions under which the work took place, and the operating assumptions underlying both the design of the project and the interpretation of its results. In other words, research readers are cautious consumers. Readers continually weigh the merits of the research and of the written argument as they read. The outcome of this evaluation process determines whether they accept the research as sound and important. And of course, current technologies provide forums for readers to take their active participation a step further, by posting their individual readings—their interpretations and evaluations—for others to see via blogs and other post-publication commenting features (Casper 2008).

4.12 How Reviewers Evaluate Reports

In the manuscript review system, the process of weighing the merits of research becomes more formal and explicit. Editors and reviewers must evaluate the merits of the research not just for their own edification but for other members of the field as well. They are making the decision of whether to read or not to read on behalf of the larger community; the outcome of their deliberations determines whether the wider community gets to see the paper at all. As we discussed in Chapter 1, the peer-review process is the mechanism by which the scientific community monitors the integrity of its work—in effect, "filters" the work of individuals. Despite the concerns we explored in Chapter 3, the peer-review system remains a formidable structure, theoretically enabling the "volatile microcosm of individual scientists" to contribute to the "stable macrocosm of the scientific enterprise" (NAS 1989, p 10).

The logistics of the peer-review (or "peer-referee") system are relatively straightforward. Most journals publish their procedures and at least a tentative timetable in their instructions for authors. Authors submitting their work to *Nature*, for example, are told that the paper is first reviewed by a member of the editorial staff, who decides whether the research will be of significant interest to *Nature*'s interdisciplinary audience (*Nature* 2008c). If the paper does not pass this initial assessment, the authors are notified immediately, usually within a week. Papers that do pass then qualify for peer review and are reviewed by two or more referees, who are chosen on the basis of their expertise in the area, their lack of connection to the authors, and their availability to complete the review in a specified time period. Reviewers submit their reviews using an online manuscript tracking system. Once the reviews are received, the editor makes a decision on the basis of their advice, choosing one of four options: (1) accept (sometimes with editorial revisions); (2) invite authors to revise to address specific concerns before a decision is made; (3) reject, but invite authors to resubmit after completing further work; (4) reject outright (http://www.nature.com/authors/editorial_policies/peer_review.html; see this website for further information about *Nature*'s review process.)

The vast majority of scientific papers undergo significant revision in response to peer review. At the *Astrophysical Journal* "fewer than 3% of reviewers' reports recommend acceptance... without significant revision" (http://www.journals.uchicago.edu/page/apj/guide-ed.html). Such a figure testifies to the extent of the scientific community's reliance on the peer-review system as a critical component of the scientific writing process. The elaborate editorial systems in place at *Nature*, *Astrophysical Journal*, and other prestigious journals suggest that it will likely remain so (e.g., see Harnad 1990).

There is a fair amount of consensus among journal editors and reviewers about what constitutes a publishable paper. Recall from the start of this chapter that journals clearly identify their target audience and the research areas they are interested in. It follows, then, that the minimum requirement for any paper is that it be of clear interest and importance to the readers of the journal to which it is submitted. Indeed, journal editors report that "suitability for the journal" is the primary concern when deciding whether to accept or reject a paper (Huler 1990). Lack of suitability is the most commonly cited reason for rejection of a manuscript (Davis 1985, cited in Olsen and Huckin 1991). Many journals, such as *Nature* and *Astrophysical Journal*, make the suitability assessment in the first stage of review.

You cannot begin to write a research report, then, until you've decided which journal audience you would like to reach. You can't develop a persuasive argument for the significance of your research without thorough knowledge of whom you're trying to persuade. In addition, the choice of journal dictates certain matters of presentation, from the purpose and organization of the article to, in some cases, details of style and formatting. Thus, prospective authors must understand not only the audience of the journal but also the nature of the communicative forum(s) the journal represents (Benson 1998) in order to write a paper that will be deemed appropriate for the journal and its audience. With the enormous number of papers competing for space in scientific journals (the *British Medical Journal* publishes only about 7 percent of the 7000–8000 manuscripts it receives per year [*BMJ* 2008]; *Nature*'s rate is 10 percent [*Nature* 2008b]), there is no room for papers that do not specifically address the interests of the journal's target audience and meet the expectations of its editors. (Lest new researchers despair, we point out that acceptance rates vary a great deal. The *Astrophysical Journal* (2008) reports an overall acceptance rate of 78 percent, though as noted above, all but 3 percent of articles undergo extensive revision.)

The following list of review criteria from the journal *Phytopathology* (2008; http://www.apsnet.org/phyto/submit.asp) provides a good summary of the features that reviewers are asked to evaluate and thus a good checklist for writers of research reports:

- Importance of the research
- Originality of the work
- Analysis of previous literature

- Appropriateness of the approach and experimental design
- Adequacy of experimental techniques
- Soundness of conclusions and interpretations
- Relevance of discussion
- Clarity of presentation and organization of the article
- Demonstration of reproducibility

Activities and Assignments

1. Select a research journal in your field, either print or electronic, for closer study. Examine several issues of the journal, and read the instructions for authors and other editorial information posted at the journal's website. Write a three- to four-page rhetorical analysis in which you discuss the following basic elements of communication:
   a. *Author.* Who publishes this journal? Whose research is reported there?
   b. *Audience.* Who are the intended readers? What types or levels of expertise do they have? Are they primarily researchers, policy makers, resource managers, educators, or other experts?
   c. *Subject.* What topics or kinds of topics does the journal cover? How general or specialized are these topics?
   d. *Text.* Describe the distinctive features of the text that helped you make inferences about author and audience. Do the articles have a formal or informal tone? Does the journal include more than one type of article (e.g., reports, letters, technical notes, reviews)? If so, how do these texts differ in style, tone, format, and purpose? (*Hint:* Don't overlook obvious features of the journal that might provide important information about its primary purpose and audience: the journal's title, institutions represented on the editorial board, announcements and advertisements, types of books reviewed, and so forth. If it is an online journal, who has access?)
2. Write a letter to a real or a hypothetical research collaborator in which you explain why you'd like to submit the results of your collaborative project to a particular research journal. Assume the two of you had narrowed your choices to two journals in the field. You've done some more investigating of the two journals, and you're ready to argue that one rather than the other will be the better place to report your findings. Your argument should be based on a clear comparison of the purpose, scope, and target audiences of the two journals.[12]
3. a. Using the IMRAD form as the organizational framework for your analysis, analyze the organizational structure of a research report in your field. Does this report illustrate the generic features described in Sections 4.3 through 4.7, or does it follow an alternative form? How does the form of the report reflect the goals, objects, or methods of research in this particular field?

[12]We are indebted to Christina Haas for this assignment idea.