CHAPTER 2

Writing a Review Paper

A scientific review paper is a critical synthesis of the research on a particular topic. Biologists read review papers to stay abreast of the current knowledge in a field and to learn about subjects that are unfamiliar to them.

When you are assigned to write a review paper for a biology course, you need to rely on many of the same strategies used by authors of published reviews. You are expected to address readers similar to yourself and your classmates — people with a background in the broad subject area but without specialized knowledge of your particular topic. Your aim is not only to inform, but also to evaluate and interpret. A good review still bears the stamp of the writer's own thought processes.

CHOOSING A TOPIC

Do not underestimate the importance of choosing a suitable topic. Ideally, it should be (1) interesting to you; (2) not so broad that it is unmanageable; (3) not so narrow that you can't find enough information on it; (4) not so difficult that you can't fully understand it.

A common approach is to start with a broad topic and do some general reading about it, gradually narrowing it down to a workable size. Suppose you decide to write a paper about orchids. Because orchids are a large, diverse group and much has been written about them, you will need to restrict yourself to some specific aspect of these plants. For example, you might decide to write about the unusual interactions between orchids and their insect pollinators. Eventually you might narrow your topic even further, perhaps confining yourself to only a few species or to several, similar kinds of pollination interactions.

As you narrow your topic and become familiar with the literature, you need to develop a sense of your main objectives. What question will your paper address and from what perspective? Are you shifting toward a particular viewpoint or conclusion that can serve as a main point, or thesis, for the paper? If you limit your scope and define your goals early in the project, your reading and note-taking will be more directed and your time will be more productive.

Occasionally the first topic you choose may be *too* narrow and you will have to enlarge it, or shift to a different subject altogether. Allow time for false starts, delays, and topic changes. Recognizing a good thing to write about requires thought and effort.

SEARCHING THE LITERATURE

■ Start with general references.

Before plunging into the technical literature, make sure you have a solid background. Use the library *card catalog* to locate textbooks or other references likely to include a general discussion of your topic. These will summarize the broad subject area, clarify key terms and concepts, and give you a feeling for the kinds of questions scientists have been investigating. Most texts also list additional readings on more specialized topics. Finding books through the card catalog will be frustrating if your topic does not seem to be listed. Be persistent; you may not be using the correct headings. A useful reference here is *The Library of Congress Subject Headings* (ninth edition), published by the U.S. Library of Congress, Washington, D.C. (1980). This work contains standardized Library of Congress headings for a large number of topics. Looking up your subject here will guide you to terms under which you will be more likely to find information.

Many libraries have adopted a computerized "card" catalog system, which has greatly facilitated the search process.

■ Use scientific abstracts and indexes.

These are invaluable aids in locating technical information on your topic. Both indexes and abstracts list papers published in a wide variety of journals; abstracts also provide short summaries of the papers. Each reference work has its own method of organization, which is easily understood if you spend a little time reading the instructions section for users. The effort is well worth it. The *General Science Index* and the *Biological and Agricultural Index* are good places to start if you are working with a broad

topic you need to narrow down, and if you have not had much experience with scientific literature.

General Science Index. This source indexes subjects in diverse scientific fields, including botany, zoology, physiology, microbiology, conservation, oceanography, nutrition, astronomy, and earth sciences. It lists papers in selected technical journals (for example, *Ecology*, *Evolution*, *Nature*, *Science*) as well as many nontechnical magazines (*Natural History*, *American Scientist*, *Scientific American*, *Audubon*, *Science Digest*, and so on). Nontechnical articles are good places to start if you have little background knowledge of your subject. They give an overview of the topic, list other useful references, and prepare you for the more specialized language of technical journals — which ultimately should be your major reading material. Many of these nontechnical articles are written by scientists who have also published technical papers on the same topic; later in your search, you may wish to locate these papers, too, by looking up the authors' names in another index such as *Biological Abstracts* and *Science Citation Index*.

Biological and Agricultural Index. This source is particularly useful for topics in environmental and conservation sciences, agriculture, veterinary medicine, and related areas of applied biology. It lists articles in selected biological journals (for example, *Heredity*, *American Naturalist*, and *Ecological Monographs*) as well as in more specialized periodicals such as *Crop Science*, *Tropical Agriculture*, *Water Management*, *Animal Production*, and *American Veterinary Medical Association Journal*. Beginners find it especially useful because it includes many periodicals devoted entirely to reviews. If you can locate a review paper dealing with your general subject area, you will have a better grasp of current research in the field and may pick up some clues about narrowing your topic productively. The Literature Cited section of a review paper is an excellent source of further information (see p. 42). Moreover, reading a professional review paper helps prepare you to write a review of your own.

Biological Abstracts. This reference is widely used by professional biologists. It includes five different kinds of indexes: an author index; a generic index (using the scientific names of organisms); a biosystematic index (using taxonomic groupings from the phylum level through the family); a concept index (using broad subject headings); and a subject index (based on more specific topics — key words in titles — and including the common names of organisms). These indexes list relevant papers by reference numbers. Looking up each number in an accompanying volume gives you full bibliographic information on the paper plus a short summary of its contents. If the paper sounds relevant to your topic, you can track it down and read the whole work.

Suppose, for example, you are researching a paper on cannibalism in fish. Looking up the key word, *cannibalism*, in the most recent subject

index, you find eighteen different reference numbers. Each number is preceded by the title (or part of the title) of the paper to which it refers (Fig. 1). Of these, the paper numbered 22252 ("Cannibalism in fresh water fish . . .") sounds most promising. The next step is to look up number 22252, read the abstract of the paper (Fig. 2), and decide if it is relevant to your topic. In this case the abstract suggests the paper contains useful information, and you would be wise to look at the paper. In practice, you may need to skim the abstracts of many papers listed under a particular key word, because it is not always possible to gauge a paper's contents from the portions of titles appearing in the subject index. Remember, too, that you will need to define the scope of your literature search by deciding how far back in time to search for papers on your topic.

Science Citation Index. If you already know of one paper relevant to your topic, you can use this work to locate other, more recent papers by authors who have mentioned (or *cited*) it. Chances are that those authors have written about the same subject. First, look up the known paper (say it's by J. L. Jones in 1970) under the author's name in the *Citation Index*, starting with the most recent volume and working backwards. You may find one or more references to other authors who have cited Jones (1970) in their own works. Full bibliographic information on these papers will be given in an accompanying volume, the *Source Index*. You can then go to the appropriate journals for the papers themselves.

There are several other ways to use the *Science Citation Index*. For example, if you suspect that J. L. Jones has recently published other papers on the same topic, you can use the Source Index on its own to find these, listed under Jones's name. If you know that scientists at Northwestern Medical School in Chicago are particularly interested in the contraceptive effects of breastfeeding, you can use the *Corporate Index*, which lists articles all originating at the same institution. Finally, if you have thought of one or more key words pertaining to your topic, you can look each one up in the *Permuterm Subject Index*, which lists *pairs* of key terms (some of which may be relevant to your research) along with recent articles whose titles include both words in the pair.

JUVENILE ADULT INDEPT	CANNIBALISM	OBSERVATIONS OF INTRA	20327
ON DENSITY CLUTCH SIZE		THE BIOLOGY OF THE KES	95322
N CETACEAN PREDATION		THE STATUS OF THE CUT	2203
ATION INHERITANCE OF		BEHAVIOR IN NOCTURNI LA	75106
ANDIBULAR GROWTH RATE		COMPETITION DENSITY DE	84359
CALLING BEHAVIOR EGG		EMBRYONIC DEVELOPMEN	116962
ZOAN FUNGI PREDATION		FEEDING WHITE TAIL DISEA	22507
PERATURE PHYSIOLOGY		IN FRESH WATER FISH HCT	22252
L DYE INDUSTRY ISRAEL		IN MURICID SNAILS AS A P	27511
AFTIVE SIGNIFICANCE OF		IN STICKLEBACKS GASTER	95414
CLOPS INFLUENCING EGG		ON THE LAND SNAIL AURIANT	22283
RODUCTIVE BENEFITS OF		IN THE MOSQUITOFISH GA	105988
DESTRUCTIVE PARENTAL		IN THE PRIMITIVE ANT AM	22246
NUSTOMATIDAE) CHOKEN		LIFE CYCLE SCANNING EL	118867
ALDES AEGYPTI LARVAE		MORTALITY IMPORTANCE	22582
ECAPOD DIEL MIGRATION		SEASON JUVENILE ADULT	32987
MALE SEASON BEHAVIOR		SPAWNING FOOD AND FE	32275
PULATION COMPETITION		TEMPERATURE DEVELOPM	52677

FIGURE 1. Entry from subject index of *Biological Abstracts*.

22252. MEHROTRA, B. K. and KUM KUM HATHI. (Zool. Dep., Jodhpur Univ., Jodhpur-342001, India.) ZOOL ORIENT 2(1/2): 69-70. 1985[recd. 1986]. **Cannibalism in fresh water fish *Heteropneustes fossilis*.**— Cannibalism in *H. Fossilis* was reported during the Laboratory studies of this fish. At a temperature of 18-25° C cannibalism occurred during fasting when the fishes were being prepared for physiological experiments.

FIGURE 2. Abstract from *Biological Abstracts*.

Current Contents. This source indexes recent articles in a variety of life sciences, including biology, agriculture, and medicine, by reproducing the tables of contents of numerous journals. If you have found one or more journals that tend to publish papers on your topic, then *Current Contents* gives you a convenient way to keep up to date on the latest literature.

This reference also includes authors' addresses, enabling you to contact an author directly to request a copy of the paper if the journal is unavailable to you. Authors usually furnish reprints gladly and without charge as long as their supply lasts. You can also order a photocopy of the paper through the interlibrary loan system of your library. It may take as long as several weeks to obtain sources using either method, so allow plenty of time.

The following are other useful references for papers in biology and related fields:

Aquatic Sciences and Fisheries Abstracts
Chemical Abstracts
Environment Index
Index Medicus
International Nursing Index
International Pharmaceutical Abstracts
Oceanic Abstracts
Pollution Abstracts
Psychological Abstracts
Wildlife Review
Zoological Record

■ Use the Literature Cited section of relevant papers to find additional sources.

One of the most efficient ways to expand your list of references is to take advantage of the experience of established authors. Each time you find a useful paper on your topic, read its Literature Cited section carefully. You may discover many titles that are relevant to your search. The author's comments about these works in the Introduction or Discussion of the paper may give you further clues about their contents, perspective, or significance.

■ Consider a computer search.

Most libraries offer computerized searches of online data bases such as BIOSIS (BioScience Information Service), AGRICOLA (Agricultural Online Access), CAB (Commonwealth Agricultural Bureau), and MEDLARS (Medical Literature Analysis and Retrieval System). Computer searches are usually done by a reference librarian. You provide several key words or search terms pertinent to your topic, and within several minutes the computer provides a list of relevant references. Some search services also supply abstracts or give you the opportunity to order the articles themselves via computer terminal.

A computer search strategy must be planned carefully. If the key words are too broad or if a particular word has more than one meaning, the computer may retrieve hundreds of titles, of which only a few will be useful. If the key words are relatively specific, you may get a high proportion of useful sources but miss some that give a broader view of the topic. Also remember that no computer search can give you every possible reference. There is always the possibility that some useful informarion may be hidden in an obscure book or journal. Only a thorough manual search, combined with good luck, may lead you to such a reference. Moreover, existing data bases contain only relatively recent literature. For topics that require a historical approach or lean heavily on literature prior to the 1960s, a computer search alone will be inadequate.

■ Record full and accurate information about your sources.

Keep a master list of all rhe references you used. Some people do this on whole sheets of paper; others list each source separately on an index card, so that when it is time to assemble the Literature Cited section, the cards can be easily shuffled and arranged in the proper order.

Learn the kinds of bibliographic information you will need to report for each kind of reference you use (see Chapter 4). If you are not sure whether certain information is essential, write it down anyway. It is easier to omit unneeded material when you eventually type your references than to spend time searching for missing publication dates or page numbers.

Photocopy all articles you think will be important sources for your paper. Even if you take good notes, you probably will need to reread part or all of the key sources on your subject before you finish researching your topic. If an article seems only peripherally related, or if you are not sure about its relevance, you may wish to photocopy only the Abstract. Jotting down a few notes about the paper's contents or perspective will allow you to return to it later if necessary. Always write full information

about the source directly on the photocopy so that you are never in doubt about its origin.

■ Be discriminating in your use of sources.

It is important to understand the distinction between *primary* sources (reports of original findings or ideas) and *secondary* sources (review articles or books based on primary references). As a review, your own paper should rely mostly on the primary literature, that is, on research papers in biological journals or in edited collections of articles. This means that although you should use encyclopedias, articles for the lay reader, lab manuals, and textbooks as sources of background knowledge, they should not be major sources of information for your paper. Cite such sources rarely, *if at all*. The same applies to reviews in scientific journals; these are invaluable summaries and introductions, but they still report knowledge secondhand. If they mention research findings that sound relevant, look up the original articles and read them yourself. The quality of your review paper depends, in part, on the sophistication of your literature search and on your ability to synthesize and interpret primary sources in your own way.

TAKING NOTES

■ Avoid plagiarism: take notes in your own words.

Plagiarism is the theft of someone else's words, work, or ideas. It includes such acts as (1) turning in a friend's paper and saying it is yours; (2) using another person's data or ideas without acknowledgment; (3) copying an author's exact words and putting them in your paper without quotation marks; and (4) using wording that is very similar to that of the original source, but passing it off as entirely your own.

This last example of plagiarism is probably the most common one in student writing. Here is an example.

ORIGINAL PASSAGE

A very virulent isolate of *Alternaria mali*, the incitant of apple blotch, was found to produce two major host-specific toxins (HSTs) and five minor ones in liquid culture. The minor toxins were less active than the major ones, but were still specifically toxic to the plants which are susceptible to the pathogen.

(Kohmoto, Kahn, *et al.* 1976, p. 141)

PLAGIARIZED PASSAGE

Kohmoto, Kahn, et al. (1976) found that a very virulent isolate of Alternaria mali, the incitant of apple blotch disease, produced two main host-specific toxins, as well as five minor ones in liquid culture. Although the minor toxins were less active than the major ones, they were still specifically toxic to the susceptible plants.

Although the writer has altered a few words here and there, the second passage is strikingly similar to the original. *It is still plagiarism if you use an author's key phrases or sentence structure in a way that implies they are your own, even if you cite the source.* The only way to make this passage "legal" as it now stands is to enclose everything retained from the original wording in quotation marks. Better yet, the writer should put the whole passage in his or her own words and word order.

Plagiarism of this kind is usually unintentional, the result of poor note-taking and an incomplete understanding of the ethics of research and writing. Typically the problem arises when you lean heavily on notes that consist of undigested passages copied or half-copied from the original source. These become the source of all the information and ideas for your paper. When you sit down to write the first draft, it is all too easy for this material to end up barely changed as the backbone of your paper. Thus, your text becomes an amalgamation of other people's words disguised as your own. Even if you cite references for the facts and ideas, you are still guilty of plagiarism because the wording is not completely yours.

Another problem with this kind of note-taking is that it consists of reading without thinking. It allows you to speed through a stack of references without necessarily understanding the material. It conflicts with your major purpose in writing a review paper: to evaluate and interpret information on a subject. You need to start making judgments, comparisons, and contrasts while you are still working with the original sources; otherwise, your prose is just a mosaic of other people's material. Your paper, like good published reviews, should be more than just a sum of its parts.

Form the habit of taking notes mainly in your *own* words. If you are not used to doing this, you may be frustrated by the additional time it takes. However, once you start the first draft, these notes will save you much time and effort. You will have already worked through difficult material, weeded out many inconsistencies, responded to the conclusions of other authors, and made connections among related ideas. Much of the preliminary work will have already been done.

To take notes effectively you need to understand how to *summarize* and *paraphrase* material. A summary expresses the important facts and ideas in fewer words than the original; for example, the abstract of a research paper is a summary. A paraphrase expresses certain facts or ideas in different

wording — your own — but usually in about the same number of words as the original. Both require that you understand the material fully before you write about it.

■ Use an orderly system.

A common method is to use index cards, putting one idea or group of related ideas from a single source on each card. The cards thus contain manageable units of information and can be shuffled around at will as you organize your paper. However, such a method can be bulky and cumbersome, and many people feel constrained by the small size of the cards. Scientific topics often require longer, more detailed notes that cannot fit on index cards.

An alternative method is to take notes on whole sheets of paper, writing on just one side so that you can cut, paste, and arrange notes later as you prepare the first draft. The backs of computer printouts are excellent for note-taking; their large size allows you to add comments or other additional notes in the margins as you go along.

Obviously, you need not take notes in complete sentences. In fact, if you try to restrict yourself to succinct phrases, you'll be even less likely to reproduce the exact wording of the original. If the author's own words *are* indispensable, enclose them within quotation marks along with the page number of the source. Do this for entire passages you wish to preserve, as well as for key words or phrases mixed in with your own notes:

J. concludes that "despite the predictive power and elegance" of the scientific method, it can give us only a "rough approximation" of what the natural world is like (Johnson 1933, p. 4).

You also need a foolproof method to distinguish between an author's ideas and your own. For example, you might use a yellow marker to highlight your ideas, or put your initials, the word *me*, or some distinctive symbol in front of any speculations and conclusions that are strictly your own.

B. suggests that light availability is the most important factor here. (me) What about moisture requirements? Not discussed.

■ Be selective.

You will waste time and effort if you take copious notes on every source you encounter. Read first; take notes only when you have decided that the reference may be useful. Start with a short summary of the author's most important findings. Once you have narrowed your topic, you can return to the most pertinent material and paraphrase where necessary. Resist the temptation to copy out the Abstract of a paper. You will accomplish more with your own words, and you can always photocopy the Abstract (or the whole paper) to consult later, if necessary.

If you are not used to looking at biological journals, you may find research papers hard to read and understand. You may vacillate between taking notes on everything and taking none at all. Here are some guidelines to help you get the most out of a scientific paper.

1. Read the Abstract first. This will give you an overview of the study and help you decide whether to read the rest of the paper. Don't feel intimidated by abstracts containing unfamiliar terms or ideas. Often the Introduction and Discussion sections of the same papers are easier to understand.

2. If the paper seems relevant, read the Introduction carefully. Be sure you understand *why* the author conducted the research. What were the major hypotheses or predictions? Authors generally end the Introduction with a brief statement of their objectives. How are these relevant to your objectives? Once you start reading a scientific paper carefully, you need to be sure of your rationale for including this particular reference in your paper. Do not take notes on everything; instead, build on the notes you already have from other sources. Organize your reading and your thinking around the specific aspects of this paper that relate to the direction your research is taking.

3. Skim the Materials and Methods. Unless your paper involves a close examination of the methodology in a particular field, you need not understand an author's procedures in detail. Instead, try to summarize the methods in a few sentences.

4. Read the Results carefully. Pay particular attention to the author's accompanying remarks about figures or tables; these will help you understand his or her reason for including them. Do not panic if you don't uderstand the quantitative details. Focus first on the major qualitative findings. Authors often summarize these in topic sentences (see p. 97). Remember to be selective. Do not paraphrase the whole Results section; instead, summarize the findings that are most relevant to your paper.

5. Pay particular attention to the Discussion. Understand the author's argument. How do the data support his or her conclusions? Are these conclusions in accord with other work in the field? What does the author imply is the major contribution of this study? How can you use this paper

In summary, when you work with biological literature do not get sidetracked. It is easy to feel overwhelmed by the specifics of each author's study and lose sight of the broad picture. Keep your own paper in mind. Get a general grasp of each author's research; then take more detailed notes on whatever aspects are relevant to your objectives. Finally, remember that the importance of a particular article may not be immediately apparent. You may need to skim through many papers at first to get your bearings and return later to those that are most central to your topic.

PRESENTING YOUR MATERIAL

■ Sketch out a rough plan or make an outline.

Biological review papers are not as standardized in their format as research papers; their organization depends largely on the subject and the writer's objectives. However, most reviews have an Introduction, a body (not labeled as such, but often with headings and subheadings), a Conclusions section, and a Literature Cited section. Some have a Summary at the end. Many start with a short Table of Contents that functions as an outline to the paper. Some have an Abstract, which summarizes the major points covered and states the scope and purpose of the review.

The best way to familiarize yourself with the structure of a review paper is to look through several on topics in your general field. Many journals, such as *The Biological Bulletin* and *American Midland Naturalist*, publish review articles in addition to research papers. Other journals specialize entirely in reviews; these include *The Botanical Review*, *Physiological Reviews*, *Psychological Review*, *The Quarterly Review of Biology*, and various annually published volumes of reviews, such as *Annual Review of Ecology and Systematics*, *Annual Review of Microbiology*, and *Annual Review of Genetics*.

Before you plunge into the first draft, you will need a tentative plan. This can range all the way from a rough sketch of the order of topics to a formal, detailed outline. Some people feel hemmed in by outlines and prefer to do much of their organizing as they work out the first draft. (These are the writers who, if ever asked to produce an outline, do so *after* they have written at least one draft of the paper.) Other people depend on a fixed plan right from the beginning to organize their thoughts. There is no one correct way to plan a review paper. You must decide what kind of organizational method suits your own writing style.

At some point in the writing, you can use your outline or plan to sketch out the Table of Contents, which in long review papers is an enormous aid to the reader. (Short reviews can do without a Table of Contents as long as the material is still well organized.) Here is the Table of Contents for a student review paper in animal behavior:

Note the use of headings and subheadings in this paper to give order to an otherwise unwieldy amount of material. Subdividing the text may also make the paper easier to write because you can tackle one chunk of material at a time. Be sure to use a consistent method in the text to designate the various sections — for example, major headings can be typed in capitals and centered on the page; subheadings can be put in boldface and typed flush with the left margin.

■ Introduce the subject, explain your rationale, and state your central question, objectives, or thesis.

These three tasks need to be accomplished in the Introduction. As in a research paper, an effective strategy is to start with broad statements, explanations, and definitions that orient and educate the reader. Then work down to more specific issues. Why is this subject important? What approach have you taken? Will you be giving a comprehensive summary or one that is more limited? End the introduction with a clear statement of the question you will address or the main point you wish to convey to the reader. Your objectives may be fairly specific — for example, to show that certain kinds of early childhood experiences predispose adolescent girls toward anorexia. Or you may wish to assess the current state of research on a particular problem, for instance, current treatment methods for AIDS, with the aim of making predictions about the next decade.

The length of the Introduction depends on your subject and the kind of coverage you plan to give it. An 8-to-10-page review might need only a single succinct paragraph to introduce it. A longer paper might require a whole page. Generally, one or two paragraphs are appropriate. Readers will soon become confused if you do not tell them your objectives fairly early in the paper.

Here is the Introduction from the first draft of a term paper for a

molecular biology course. The numbers in parentheses refer to sources in the Literature Cited section (see discussion in Chapter 4). How might this student paragraph be improved?

> Many different articles were read about the molecular genetics of human growth hormone. This paper will focus especially on hGH deficiencies. Human growth hormone (hGH) is a polypeptide hormone, produced from within a gene cluster on chromosome 17, that controls much of the physical growth of the infant and child (1, 2). Since time is limited, this paper cannot cover all possible aspects of hGH, so a narrower approach has been taken.

In this Introduction two sentences, the first and the last, say nothing essential. The reader assumes you have read about your topic, and you can easily show how you plan to narrow the focus by stating exactly what this focus is. Remember that the Introduction gives you your first chance (perhaps your only chance) to interest the reader. Obviously your instructor must read the paper whether he or she wants to or not, but if you get off to a forceful and interesting start, the paper will have a much better effect.

A second problem with the paragraph is that we don't get a clear sense of the writer's *specific* purpose or rationale. We know that the paper will focus mainly on hGH deficiencies, but we do not know how or why. If the writer fails to portray the subject as important or intriguing, it is difficult for the reader to feel it is.

Here is the second-draft version of the introduction. Notice how the writer has omitted the unnecessary sentences and filled in the "gaps" by expanding the more important parts of the original. The revised Introduction conveys a clearer idea of what this paper is about and why this subject is interesting.

> Human growth hormone (hGH) is a polypeptide hormone, produced from within a gene cluster on chromosome 17, that controls much of the physical growth of the infant and child (1, 2). Deficiency of hGH, a heritable disorder, can result in infantile dwarfism and retardation (3, 4, 5). New research methods, including recombinant DNA technology, have made it possible to determine the molecular basis of such deficiencies. In this paper, I will summarize current knowledge of the molecular genetics of hGH and suggest ways in which continued research may help physicians treat infants with a deficiency of this hormone.

■ Build a focused discussion.

Many student review papers are little more than summaries, boring ones in which the writer has retreated from the reader's sight. It is not enough just to regurgitate the contents of a series of papers one by one. You need to *relate* this material to your principal objectives. Present your information selectively, and use it to support or illustrate the statements you wish to make. A good review interprets the literature from the writer's own informed perspective and gives the reader a sense of integration, development, and focus.

The following paragraph is from a paper on the adaptive value of cannibalism in animals. Notice how the author uses examples from the literature to illustrate and develop the generalization in the first sentence.

> Following the reasoning of West Eberhard (1975), we may predict that cannibalism may be more likely when the potential victims are unusually vulnerable and easily obtained as food. Such individuals are, in fact, the predominant victims of cannibalism in many species. For example, most cannibalism in Tribolium is performed by larvae and adults on the defenseless eggs and pupae (Mertz and Davies 1968). Pupae are also eaten by larvae in caddisflies (Gallepp 1974), and injured or weak immature stages are devoured by older nestmates in many species of social ants (Wilson 1971). In crows (Corvus corone), cannibalism of eggs and nestlings by intruding adults is more frequent when the parents are absent from the nest, leaving their young more vulnerable to attack (Yom-Tov 1974).

The next passage is from a paper for a plant pathology course. It discusses host-specific toxins, substances produced by pathogenic (disease-producing) fungi that attack certain plants. Notice how the author presents

selected information from the literature to critically examine a particular hypothesis. The writing conveys authority and a thorough familiarity with the material.

> Changes in the permeability of host cell membranes after being exposed to toxins suggest that these substances may bind to a receptor site in the cell membranes of susceptible hosts. Strobel (1974) claims to have found such a receptor site in the membranes of sugarcane cells treated with helminthosporoside, a toxin isolated from the pathogenic fungus Helminthosporium sacchari. The site contains a protein of molecular weight 48,000 daltons that specifically binds the toxin. Strobel has proposed that the binding of the toxin stimulates the activity of an adjacent membrane-bound enzyme, potassium-magnesium ATPase, which maintains ion balance across cell membranes. Such stimulation could disrupt the membrane's selectivity to ions, resulting in the characteristic symptom of electrolyte leakage.
>
> Several authors have criticized Strobel's methodology and interpretations. For example, Wheeler (1976) doubts that the preparation used for helminthosporoside assay and structure determination was sufficiently free from impurities, and he argues that some experiments lacked sufficient replication. Others have said that the toxin-binding data were not graphed correctly and that regraphing them suggests the binding activity is, at best, weak (see, for example, Hanchey and Wheeler 1979). These and other criticisms have been reviewed by Yoder (1980).

■ Document your paper thoroughly.

Whenever you refer to another author's work or ideas, cite your sources using conventional methods of literature citation (see Chapter 4). In a review paper (as in the Introduction and Discussion of a research paper),

you need to cite references repeatedly. Look at the following sentence from a review by Hepler and Wayne (1985, p. 412).

> Red light triggers a large array of physiological and developmental events that require Ca^{2+}, including chloroplast rotation in *Mougeotia* (55, 78, 247–249), spore germination (254–256) and cell expansion (37) in *Onoclea*, leaflet closure in *Mimosa* (22, 23, 237), root tip adhesion in *Phaseolus* (229, 279), peroxidase secretion in *Spinacia* (113, 164, 165), membrane depolarization in *Nitella* (261), as well as activation of NAD kinase (1, 218, 232) and inhibition of mitochondrial ATPase (212).

Using many citations may seem strange at first. You may feel they impede the flow of your writing. However, readers of scientific papers are accustomed to such interruptions, and you will get used to them, too. Remember that literature citations serve an important function: they tell readers where to find additional information. Careful documentation also reflects the thoroughness of your literature search as well as your honesty in acknowledging the sources of your material.

■ Use quoted material sparingly.

Many beginning writers, unsure of their own voices or uncomfortable with the material, tend to fall back on quotations to get them through "rough spots" in the paper. Sometimes they construct whole paragraphs around a series of quotations from different authors, stringing these together with a few scattered phrases or sentences of their own. The text thus becomes a collection of other people's words:

> Studies of the Baltimore butterfly (*Euphydryas phaeton*) showed that "larvae occupied communal nests of various sizes" and "commonly cannibalized unhatched eggs in the same colony" (Monti 1950). "In both field and laboratory tests, there was a higher incidence of cannibalism by larvae occupying large colonies" (Monti 1950). Also, "cannibalistic acts occurred at a higher frequency under conditions of food shortage," when the larval foodplant, turtlehead, "was in short supply or extensively defoliated" (Mulry 1960).

In such a passage the reader loses track of the writer and the writer loses authority. The quotations do not enhance the text — they detract from it, suggesting that the writer hasn't come to terms with the material and is either too inexperienced or too lazy to use his or her own words. Biological authors rarely use quoted material, relying instead on careful, concise paraphrases or summaries; you should do the same. For example, the quotation-ridden passage above can be rephrased and condensed in the author's own words:

> Studies of the Baltimore butterfly (*Euphydryas phaeton*) showed that cannibalism of eggs by the communal larvae was more frequent in large colonies than in small ones (Monti 1950). Cannibalism also increased when the larval foodplant, turtlehead, was scarce (Mulry 1960).

When *is* it appropriate to use the exact wording of an author? Occasionally you may wish to include a quotation to establish or emphasize an important point or state a precise definition. Sometimes you may feel that an author's exact words are indispensable in conveying a particular viewpoint or idea:

> Bem (1981, p. 255) defines a *schema* as a "cognitive structure, a network of associations that organizes and guides an individual's perception."
>
> To Eiseley (1961), Darwin was "the man who saw the wrinkled hide of a disintegrating planet, glyptodonts and men, all equally flowing down the direction of time's arrow; he was a master artist and he entered sympathetically into life" (p. 351).
>
> In his controversial book, *The Naked Ape*, Morris (1967, p. 211) concludes that the survival of the human species depends on an increasing awareness of our biological heritage:
>
> > We must somehow improve in quality rather than in sheer quantity. If we do this, we can continue to progress technologically in a dramatic and exciting way without denying our evolutionary inheritance. If we do not, then our suppressed biological urges will build up and up until the dam bursts and the whole of our elaborate existence is swept away in the flood.

When you do use quoted material, cite the source in the text using either the name-and-year or number method (see Chapter 4). Some biological authors include the page number of the book or article in the citation; others do not. Be sure to reproduce the quoted material *exactly*. Introduce and punctuate quotations properly, using the following rules.

1. Do not substitute single quotation marks (' ') for double ones (" "). The former are restricted to quotations within other quotations. (In British usage, single quotation marks are used first; double quotation marks are used to set off quotations within quotations.)
2. A short quotation can be integrated into the text. Make sure it fits in grammatically with the rest of the sentence.

> Dawkins (1976, p. 206) suggests that memes, as units of cultural transmission, can replicate themselves by "leaping from brain to brain via a process which, in the broad sense, can be called imitation."

For a quotation longer than four typed lines in your paper, omit the quotation marks and use a colon to introduce it. Indent each line of the passage five spaces from the left margin, but keep it double-spaced.

3. Place periods and commas *inside* the quotation marks; semicolons and colons go *outside*.

> Jones (1987, p. 2) calls Davidson's explanation "the most exciting model of this century."
>
> Davidson's explanation is "the most exciting model of this century," according to Jones (1987, p. 2).
>
> Jones (1987, p. 2) considers Davidson's explanation "the most exciting model of this century"; unlike previous models, it gives rise to far-ranging predictions about how major evolutionary changes occur.

If exclamation marks, question marks, and dashes are part of the quoted material, put them inside the quotation marks. If they are part of your own sentence, put them outside.

4. If you need to interrupt a quotation to omit one or more words, indicate the omission by an ellipsis (three periods, separated by spaces). If the ellipsis falls at the end of a sentence, put a period after it.

> Morris (1976, p. 211) concludes that humans must "somehow improve in quality. . . . If we do this, we can continue to progress technologically in a dramatic and exciting way without denying our evolutionary inheritance."

5. If you insert clarifying or explanatory material into a quotation, put such material in brackets [ ].

> Morris (1976, p. 211) concludes: "If we do this [improve in quality], we can continue to progress technologically in a dramatic and exciting way without denying our evolutionary heritage."

■ End with general conclusions.

Despite the importance of an effective Conclusions section, this part of a review paper gets the least attention from many beginning writers. By the time they reach this point, most writers are worn out and feel they have nothing more to say. They are so anxious to be done with the paper that they make a hasty retreat, summing up the topic in a sentence or two and then coming to a weary stop.

> Thus, the role of host-specific toxins in plant disease is a complex topic. There are still many questions for scientists of the future to answer.

The following student paragraph, however, summarizes the major points in the paper and adds a final perspective:

> In conclusion, current evidence shows that resist-
> ance or susceptibility is an inborn trait of a

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plant. Some plant pathogenic fungi can produce tox-
ins that, by disturbing host physiological func-
tions, affect the onset and development of plant
disease. However, it is not clear whether these
substances have a primary role in determining re-
sistance or susceptibility. Perhaps some other
mechanism may determine specificity, and toxins may
exert their damaging effects secondarily. Future
research on host-specific toxins will help to answer
this question.
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As shown above, a Conclusions section consolidates and strengthens the relationships, patterns, and arguments you have been building in the body of the paper. However, a good Conclusion should do more than merely summarize; it must also *conclude* something. Assuming that you have adequately addressed the topic, now you must answer such questions as "So what?" or "What next?" What is the significance of everything you have just told the reader? What conflicts still need to be resolved? What research must still be done? What might we expect to happen in the future?

Do not, however, introduce *new* information that really belongs in the body of the paper. Avoid complex questions or issues that you can't fully address. You do not want to throw readers off course or leave them hanging in mid-air. On the contrary, you want to tie up loose ends and finish with a satisfying sense of closure.

There is no set length for a Conclusions section. In published reviews, it varies from a single concise paragraph to a page or more of text. The length depends on the topic, the author's aims and depth of coverage, and any length restrictions on the paper. Plan ahead as you are drafting the manuscript so that you have enough space, time, and energy to end your paper effectively.

CHAPTER 3

Using Tables and Figures

The text of scientific papers is often supplemented with tables and figures (graphs, drawings, or photographs). Such materials can convey certain types of information much more effectively than words alone. A table can help you compare the results of a variety of chemical analyses. A graph can illustrate the effect of temperature on the growth of bean seedlings. A line drawing can depict an aggressive interaction between two fish, and a photograph can record important features of your study site.

It is not true, however, that tables and figures are essential in a scientific report. Biology students sometimes think that *all* data must be tabled or graphed to produce "professional" results. Even in published papers, unnecessary tables or figures sometimes find their way into print, wasting the reader's time and raising printing costs. Your credibility as a scientist will suffer if you use tables or figures just to impress the reader, when simple text will do as well or better.

A crucial task in scientific writing is deciding on an effective way to display whatever relationships, patterns, and trends are present in the data. You need a good sense of what quantitative data you are seeking and why. What statistical analyses are most appropriate to address the question you have asked? This concern should have high priority in the early stages of your research, not just at the end when there is no time to compensate for mistakes, problems, or oversights.

A second and related concern is how to incorporate your quantitative data smoothly into the manuscript. Can your measurements and statistical analyses be summarized easily in the text, or is a table called for? Would a graph be more effective than a table? Rarely is there only one way to depict a given data set; however, one way may be superior to others. You