APPENDIX A

Scientific Writing

For the scientific enterprise to be successful, scientists must communicate their work. Major scientific findings are never kept secret. Instead, scientists share their ideas and results with other scientists, encouraging critical review and alternative interpretations from colleagues and the entire scientific community. Communication, both verbal and written, occurs at every step along the research path. While working on projects, scientists present their preliminary results for comments from their coworkers at laboratory group meetings and in written research reports. At a later stage, scientists report the results of their research activities as a poster or oral presentation at a scientific meeting. Then the final report is prepared in a rather standard scientific paper format and submitted for publication in an appropriate scientific journal. At each stage in this process, scientists encourage and require critical review of their work and ideas by their peers. The final publication in a peer-reviewed journal generally promotes additional research and establishes this contribution to current knowledge.

One of the objectives of every lab topic in this manual is to develop your writing skills. You will generate and write hypotheses, results, observations, answers to questions, and more, as one way of learning biology. Also, you will practice writing in a scientific paper format and style to communicate the results of your investigations. By the time you have completed the lab topics in this manual, you will have written the equivalent of at least two complete scientific papers.

As you investigate the different lab topics, you will make observations, ask questions, and propose hypotheses. You will design and conduct experiments using procedures of your own design or following procedures in the manual. You will record results, designing tables and graphs to present your data in a logical and organized format. You will then interpret results and come to conclusions based on your hypotheses. This process is reflected in the design of a scientific paper and the format you will use for your laboratory papers. Each paper will be divided into sections that reflect these activities.

A scientific paper usually includes the following parts: a **Title** (statement of the question or problem), an **Abstract** (short summary of the paper), an **Introduction** (background and significance of the problem), a **Materials and Methods** section (report of exactly what you did), a **Results** section (presentation of data), a **Discussion** section (interpretation and discussion of results), and **References Cited** (books and periodicals used). A **Conclusion** (concise restatement of conclusions) and **Acknowledgments** (recognition of assistance) may also be included.

We propose that you practice writing throughout the biology laboratory program by submitting individual sections of a scientific paper. Although your

instructor will determine which sections you will write for a given lab topic, we outline a sample writing program below.

Scientific Writing Program

Examples of Individual Sections of a Scientific Paper for Suggested Lab Topics:

Title Page and Materials and Methods for Lab Topic 1, Scientific Investigation

Results for Lab Topic 2, Enzymes

Discussion for Lab Topic 4, Diffusion and Osmosis

Results plus Discussion for Lab Topic 5, Cellular Respiration and Fermentation

Introduction and References Cited for Lab Topic 6, Photosynthesis

Your instructor will evaluate each of these sections, pointing out areas of weakness and suggesting improvements. By the time you have completed these assignments, you will have submitted the equivalent of one scientific paper.

Having practiced writing each section of a scientific paper in the first half of the laboratory program, you will then write one or two complete laboratory papers in scientific paper format during the second half of the laboratory program, reporting the results of experiments, preferably those that you and your research team have designed and performed. Because performing the experiment will be a collaborative effort, you and your teammates will share information for the Materials and Methods and Results sections of your reports. However, the Introduction, Discussion, and References Cited (or References) sections must be the product of your own personal library research and creative thinking. If you are not certain about the level of independence and what constitutes plagiarism in this laboratory program, ask your instructor to clarify the class policy. *In the most extreme case of plagiarism, a student presents another student's report as his or her own. However, representing another person's ideas as your own without giving that person credit is also plagiarism and is a serious offense.*

A more detailed description of each section of a scientific paper follows. As you write your paper, clearly label each section (except the title page), placing the title of the section against the left margin on a separate line.

Title Page and Title

The title page is the first page of the paper and includes the title of the paper, your name, the course title, your lab time or section, your instructor's name, and the due date for the paper. *The title should be as short as possible and as long as necessary to communicate to the reader the question being answered in the paper.* For example, if you are asking a question about the inheritance patterns of the gene for aldehyde oxidase production in *Drosophila melanogaster,* a possible title might be "Inheritance of the Gene for Aldehyde Oxidase in *Drosophila melanogaster.*" Something like "Inheritance in Fruit Flies" is too general, and "A Study of the Inheritance of the Enzyme Aldehyde Oxidase in the Fruit Fly *Drosophila melanogaster*" is too wordy. The words "A Study of the" are superfluous, and "Enzyme" and "Fruit Fly" are redundant. The

suffix *-ase* indicates that aldehyde oxidase is an enzyme, and most scientists know that *Drosophila melanogaster* is the scientific name of a common fruit fly species. However, it is appropriate to include in the title both common and scientific names of lesser known species.

Place the title about 7 cm from the top of the title page. Place "by" and your name in the center of the page, and place the course name, lab section, instructor's name, and due date, each on a separate centered line, at the bottom of the page. Leave about 5 cm below this information.

Abstract

The abstract, if one is requested by the instructor, is placed at the beginning of the second page of the paper, after the title page. *The abstract concisely summarizes the question being investigated in the paper, the methods used in the experiment, the results, and the conclusions drawn.* The reader should be able to determine the major topics in the paper without reading the entire paper. The abstract should be no more than 250 words, and fewer if possible. Compose the abstract after the paper is completed.

Introduction

The introduction has two functions: (1) to provide the context for your investigation and (2) to state the question asked and the hypothesis tested in the study. Begin the introduction by reviewing background information that will enable the reader to understand the objective of the study and the significance of the problem, relating the problem to the larger issues in the field. Include only information that directly prepares the reader to understand the question investigated. Most ideas in the introduction will come from outside sources, such as scientific journals or books dealing with the topic you are investigating. All sources of information must be referenced and included in the References Cited (or References) section of the paper, but the introduction must be in your own words. Refer to the references when appropriate. Unless otherwise instructed, place the author of the reference cited and the year of publication in parentheses at the end of the sentence or paragraph relating the idea; for example, "(Finnerty, 1992)." Additional information on citing references is provided on p. 756, References Cited. Do not use citation forms utilized in other disciplines. Do not use footnotes and avoid the use of direct quotes.

As you describe your investigation, include only the question and hypothesis that you finally investigated. Briefly describe the experiment performed and the outcome predicted for the experiment. Although these items are usually presented after the background information near the end of the introduction, you should have each clearly in mind before you begin writing the introduction. It is a good idea to write down each item (question, hypothesis, prediction) before you begin to write your introduction.

Write the introduction in the past tense when referring to your experiment; but when relating the background information, use the present tense as you refer to another investigator's published work. Previously published work is considered established in the present body of knowledge.

Throughout your paper, we encourage you to use the active voice whenever possible. Doing so makes the paper easier to read and more understandable. In biology, editors of scientific journals are now suggesting or requiring use of the active voice.

In general, the Introduction is written before the Discussion; however, some authors prefer to write the Introduction last. Remember to revise the Introduction after completing your paper.

Materials and Methods

The Materials and Methods section describes your experiment in such a way that it can be repeated. This section should be a narrative description that integrates the materials with the procedures used in the investigation. Do not list the materials and do not list the steps of the procedure. Rather, write the Materials and Methods section concisely in paragraph form in the past tense. Be sure to include levels of treatment, numbers of replications, and controls. If you are working with living organisms, include the scientific name and the sex of the organism if that information is relevant to the experiment. If you used computer software or any statistical analyses, include these in the Materials and Methods section.

The difficulty in writing this section comes as you decide the level of detail to include in your paragraphs. You must determine which details are essential for another investigator to repeat the experiment. For example, if in your experiment you incubated potato pieces in different concentrations of sucrose solution, it would not be necessary to explain that the pieces were incubated in plastic cups labeled with a wax marking pencil or to provide the numbers of the cups. In this case, the molarity of the sucrose solutions, the size of the potato pieces and how they were obtained, and the amount of incubation solution are the important items to include. Do not include failed attempts unless the technique used may be tried by other investigators. Do not try to justify your procedures in this section.

The Materials and Methods section is often the best place to begin writing your paper. The writing is straightforward and concise, and you will be reminded of the details of the work.

Results

The Results section consists of at least four components: (1) one or two sentences reminding the reader about the nature of the research, (2) one or more paragraphs that describe the results, (3) figures (graphs, diagrams, pictures), and (4) tables. *The Results is the central section of a scientific paper.* Therefore, you should think carefully about the best way to present your results to the reader. The data included in tables and graphs should be summarized and emphasized in the narrative paragraph. Draw the reader's attention to the results that are important. Describe trends in your data and provide evidence to support your claims. This section also is written in the past tense.

Before writing the Results section, prepare the tables and figures. Remember to number figures and tables consecutively throughout the paper (*see Lab Topic 1, Scientific Investigation, for instructions on creating figures and tables and*

their presentation). Refer to figures and tables within the paragraph as you describe your results, using the word Figure or Table, followed by its number; for example, "(Figure 1)." If possible, place each figure or table at the end of the paragraph in which it is cited.

If you have performed a statistical analysis of your data, such as chi-square, include the results in this section.

Report your data as accurately as possible. Do not report what you expected to happen in the experiment nor whether your data supported your hypothesis. Do not discuss the meaning of your results in this section. Do not critique the results. Any data you plan to include in the Discussion section must be presented in the Results. Conversely, do not include data in the Results that you do not mention in the Discussion.

Write the Results section before attempting the Discussion section. This will ensure that the results of your investigation are clearly organized, logically presented, and thoroughly understood before they are discussed. For this reason, some scientists begin with the Results section when writing a paper.

Discussion

In the Discussion section, you will analyze and interpret the results of your experiment. Simply restating the results is not interpretation. The Discussion must provide a context for understanding the significance of the results. Explain why you observed these results and how these results contribute to our knowledge. Your results either will support or confirm your hypothesis or will negate, refute, or contradict your hypothesis; but the word *prove is* not appropriate in scientific writing. If your results do not support your hypothesis, you must still state why you think this occurred. Support your ideas from other work (books, lectures or outside reading of scientific literature). State your conclusions in this section.

Complete your Introduction and Results sections before you begin writing the Discussion. The figures and tables in the Results section will be particularly important as you begin to think about your discussion. The tables allow you to present your results clearly to the reader, and graphs allow you to visualize the effects that the independent variable has had on the dependent variables in your experiment. Studying these data will be one of the first steps in interpreting your results. As you study the information in the Introduction section and your data in the Results section, write down relationships and integrate these relationships into a rough draft of your discussion.

The following steps, modified from Gray, Dickey, and Kosinski (1988), may be helpful to you as you begin to organize your discussion and before you write the narrative:

1. Restate your question, hypothesis, and prediction.
2. Answer the question.
3. Write down the specific data, including results of statistical tests.
4. State whether your results did or did not confirm your prediction and support or negate your hypothesis.
5. Write down what you know about the biology involved in your experiment. How do your results fit in with what you know? What is the significance of your results?

6. How do your results support or conflict with previous work? Include references to this work.
7. Clearly state your conclusions.
8. List weaknesses you have identified in your experimental design that affected your results. List any problems that arose during the experiment itself that affected your results. The weaknesses of the experiment should not dominate the Discussion. Include one or two sentences only if these problems affected the results. Remember the focus of the Discussion is to convey the significance of the results.
9. You are now ready to write the narrative for the Discussion. Integrate all of the information into several simple, clear, concise paragraphs. Discuss the results; do not simply restate the data. Refer to other work to support your ideas.

References Cited (or References)

A References Cited section lists only those references cited in the paper. A References section (bibliography), on the other hand, is a more inclusive list of all references used in producing the paper, including books and papers used to obtain background knowledge that may not be cited in the paper. For your paper you should have a References Cited section that includes only those references cited in the paper. The format for the References Cited section differs slightly from one scientific journal to the next. How does an author know which format to use? Every scientific journal provides "Instructions to Authors" that describe specific requirements for this important section and all other aspects of the paper. You may use the format used in this lab manual and provided in the examples below, select the format in a scientific journal provided by your instructor, or use another accepted format for listing your references. Your instructor may provide additional instructions. Be sure to read the references that you cite in your paper.

Examples of Reference Citations

Journal article, one author:

Whittaker, R. H. "New Concepts of Kingdoms of Organisms." *Science,* 1969, vol. 163, pp. 150–160.

Journal article, two or more authors:

Watson, J. D., and F. H. Crick. "Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid." *Nature,* 1953, vol. 171, pp. 737–738.

Book:

Darwin, C. R. *On the Origin of Species.* London: John Murray, 1859.

Chapter or article in an edited book:

Baker, H. G. "Characteristics and Modes of Origin of Weeds" in *Genetics and Colonizing Species,* eds. H. G. Baker and G. L. Stebbins. New York: Academic Press, 1965, pp. 147–152.

Government publication:

> Office of Technology Assessment. *Harmful Non-indigenous Species in the United States.* Publication no. OTA-F-565. Washington, D.C.: U.S. Government Printing Office, 1993.

In the text of the paper, cite the references using the author's name and the year. For example: "The innate agonistic behavior of the male Siamese fighting fish has been widely studied (Simpson, 1968)." "Simpson (1968) has described the agonistic behavior of the male Siamese fighting fish." If there are more than two authors, use the first author's name followed by *et al.* (and others). For example: (Simpson *et al.*, 1968).

Using Information Sources from the Web

The Web can provide access to online reference resources including *Biological Abstracts, Current Contents, Medline,* and *Annual Reviews* among many others. These search tools provide access to a wide range of published papers, some of which may be available online as full text journals. For suggestions and examples of how to locate sources using the Web, see Pechenik (2001). Scientific papers published in professional journals have gone through an extensive review process by other scientists in the same field. Most scientific articles have been revised based on comments by the reviewers and the editors. Sources of information that lack this critical review process do not have the same validity and authority.

The World Wide Web (WWW) is an exciting, immediate, and easily accessible source of information. However, unlike traditional bibliographic resources in the sciences, the WWW includes websites with material that has not been critically reviewed. Your instructor may prefer that you use the WWW only for locating peer-reviewed resources or as a starting point to promote your interest and ideas. You may not be allowed to use WWW sources at all. Consult your instructor concerning use of online information.

If you do use the WWW to locate information, you should be prepared to evaluate these sites critically. Remember always to record the online address for any site you use as a reference. Tate and Alexander (1996) suggest the following five criteria for evaluating WWW sources:

1. **Authority.** Determine the author and sponsor for the WWW site. What is the professional affiliation of the author? Are phone numbers and addresses included? Is there a link to the sponsor's home page? Does the author list his or her qualifications? If the material is copyrighted, who owns the copyright?
2. **Accuracy.** Look for indications of professional standards for writing, citations, figures, and tables. Are there typographical, spelling, and grammatical errors? Are sources of information cited? Are the data presented or simply summarized?
3. **Objectivity.** Is the site provided as a public service, free of advertising? If advertising is present, is it clearly separate from the information? Does the site present only the view of the sponsor or advertiser?

4. **Currency.** Determine the date of the site and whether it is regularly revised. How long has the site existed? When was it last updated? Are figures and tables dated? Some WWW sites disappear overnight. Always record the date that you visited the site and retrieved information.
5. **Coverage.** Is the information offered in a complete form or as an abstract or summary of information published elsewhere? Is the site under construction? When was the site last revised?

We have included one suggested format for citing online information in the References Cited section of your paper. Also see the examples at the end of many lab topics in this manual. Other formats may be suggested by your instructor or librarian.

Author. *Title.* [online] available http://www.address, date accessed.

For example: Manning, G. *The Drosophila Virtual Library.* [online] available http://www.ceolas.org/fly/, 1998.

Reminders

Scientific writing should be clear and concise. This requires critical thinking and repeated revision. You should read background information carefully and critically in preparation for designing your investigation and to provide a context for your work. As you complete your investigation, you must think critically about your results and the best way to present your results. Scientific writing involves using evidence from your work and that of others to make a clear and logical argument. To be successful you must plan time for researching your topic, analyzing your results, and then revising your writing. For suggestions and examples of how to revise your work, see Chapter 5, "Revising," in Pechnik (2001).

As you begin writing your paper, refer to the following list for hints on how to make your writing stronger:

1. Write clearly in short and logical, but not choppy, sentences.
2. Use the past tense in the Abstract, Materials and Methods, and Results sections. Also use the past tense in the Introduction and Discussion sections when referring to your experiment.
3. Write in grammatically correct English.
4. When referring to the scientific name of an organism, the genus and species should be in italics or underlined. The first letter of the genus is capitalized, but the species is written in all lowercase letters; for example, *Drosophila melanogaster.*
5. Use metric units. Use numerals when reporting measurements, percentages, decimals, and magnifications. When beginning a sentence, write the number as a word. Numbers of ten or less, that are not measurements, are written. Numbers greater than ten are given as numerals.
6. The word "data" is plural.
7. Record the citation information for any references, including online sources, at the time you read the information. Refer to the citation format to record the complete citation.
8. Save a copy of your work on a disk and print a copy of your paper before turning in the original.

9. Begin writing early to allow time for revision. Simplify your writing. Delete unnecessary words. Adjectives and adverbs have limited use in describing your work.
10. Carefully proofread your work, even if your word processor has checked for grammatical and spelling errors. These programs cannot distinguish between your and you're, for example.

References

The following sources are recommended to give additional help and examples in scientific writing:

Gray, L. S., J. Dickey, and R. Kosinski. *Writing Guide.* Clemson, SC: Clemson University, 1988.

McMillan, V. E. *Writing Papers in the Biological Sciences.* New York, NY: St. Martin's Press, 1988.

Moore, R. *Writing to Learn Biology.* New York, NY: Saunders College Publishing, 1992.

Pechenik, J. A. *A Short Guide to Writing about Biology,* 4th ed., New York, NY: Addison Wesley, 2001.

Tate, M., and J. Alexander. "Teaching Critical Evaluation Skills for World Wide Web Resources." *Computers in Libraries,* Nov/Dec 1996, pp. 49–55.

Websites

Bibliography on Evaluating Internet Resources:
http://refserver.lib.vt.edu/libinst/critTHINK.HTM, 1998.

Biologist's Guide to Library Resources:
www.ase.tufts.edu/biology/bguide/, 2000.