WRITING SCIENTIFIC PAPERS IN BIOLOGY

Adapted from Cox (1990), revised by K. Larsen

Although reading the scientific literature and writing scientific papers are hard work, they are important skills you need to develop to be able to communicate as a biologist. Writing scientific papers may ultimately be one of the most satisfying accomplishments you have as a biology student. To learn how to write well, you must not only write, but you should also read scientific journal articles and use them as models for your writing. In scientific writing, you take ideas and conclusions from other works to provide background information and to support your work. The sources of these ideas must be acknowledged with citations using the "author, date" method (see "Citing references in the text" in Literature Cited section). In scientific writing you put these ideas *in your own words* and typically *do not use quotes*, yet always cite the source of these ideas.

A well-written scientific paper must fulfill two objectives: it must clearly and completely describe the procedures that were followed and the results that were obtained; it must also place these results in perspective by relating them to the existing state of knowledge and by interpreting their significance.

While you need to do all of this, you also need to write as clearly and concisely as possible. Superfluous verbiage is a hindrance to the reader and is not acceptable in scientific writing. Some examples of unclear and excessive writing include "The rats, numbering six, were...", "It can be noted that fewer...", or "The tapeworm, when in adulthood, can,...". These should simply be "Six rats were...", "Fewer...", or "The adult tapeworm can....". When editing, read your paper out loud, making sure your grammar is complete and all your statements make sense.

SCIENTIFIC PAPER FORMAT

Scientific papers should be typed. They need not (should not) be long, but should be typed using **12 point font**, **double-spaced**, on **numbered pages**. Include your **name, date, and class lab section** at the top, upper-right-hand corner of the 1st page except on Bio 490 senior projects that require a special cover page. Use a single staple in the upper left hand corner to attach sheets together. Do NOT include a separate cover page or use plastic covers. We encourage you to double-side your printout or reuse paper previously printed on the back to conserve paper.

Each laboratory report will include a **title** and five clearly labeled main sections: **Introduction**, **Methods**, **Results**, **Discussion**, and **Literature Cited**. This is not an absolute structure as some papers will be variations of this model. A brief description of the contents of each section follows below.

Lab reports for biology should be written in the first person (e.g. I/we found…). If known, you should include the scientific name(s) of each organism studied. Scientific names should always be italicized or underlined, with the genus capitalized and species lower case (e.g. *Danaus plexippus*).

Always acknowledge the sources of your information using citations. In scientific writing, direct quotes are almost never used. Instead, put the information into your own words and then cite the source at the end of each sentence as described in the "literature cited" instructions below.

If several separate experiments were conducted for a single laboratory report, it is acceptable to subdivide any or all of the above sections in your report. For example, if you were doing a lab on ponds that included a study of both biotic and abiotic factors, you may use subheadings in any section of your laboratory report to help keep your writing focused.

Write clearly and concisely, avoiding extra words that don't help get your point across. When revising read your paper out loud, making sure that your grammar is correct and all your statements make sense. See optional text "Writing Papers in the Biological Sciences" (McMillan, 2005) for helpful comments about writing and revising.

We suggest you start by writing the methods section, then results section. You are then ready to write your introduction and discussion sections.

TITLE

Titles should be specific, using the fewest possible words to adequately *describe* the contents of the paper. Include specifics such as the name of the organism studied. For example, although longer "the effect of iron on the rate of development of the fathead minnow" is much more descriptive and clearer than "fathead minnow development".

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 the background information (include citations!) that will enable the reader to understand the objective of the study and the significance of the question. The background information should make it clear *why* you did the experiment. Follow the background information with a clear statement of the question, goal(s), or objective/hypothesis of your investigation. Briefly describe the experiment performed (one or two sentences only) and the outcome you predicted. These items are usually at the end of the introduction. Always briefly state what organisms and variables were studied in the introduction. The introduction may be short (2-3 paragraphs) depending on your paper topic.

MATERIALS AND METHODS

The materials and methods section explains what was done clearly and completely. Another scientist should be able to read it and repeat your experiment. This section should be a narrative description that integrates the materials and procedures used in the investigation. Do not make lists of the materials or an outline of the steps of the procedure. Rather, write the materials and methods section concisely in paragraphs that describe each step of the experiment. Use past tense, since this section describes how you *did* your study.

Sometimes this information is covered in a laboratory manual or handout, and if so, it is may **NOT** be necessary to "copy" this procedural information into your report. Instead, simply inform the reader with a citation that you used the materials and methods specified in your laboratory manual or other source by making a proper reference to the resource. The complete citation for the resource should be included in the "Literature Cited" section of your report.

If your experimental design differed from the instructions described in the lab manual, you need to describe your methods clearly enough and completely enough to answer all basic questions about how the study was done so that another scientist could repeat your experiment. Basically answer the questions: *where?*, *when?*, and *how?* Be as specific and as concise as possible. We don't need to know you used a #2 pencil, but we do need to know what kind of organism you studied, where the work was done (describe the study area if it was a field study), what was measured, how the study was replicated, and how your results were analyzed. Make sure to describe any treatments if it was a manipulative experiment. Describe the number of replicates and any controls.

Any statistical tests used to analyze your data should also be described here, citing a source for the statistical tests, perhaps a statistics book or your lab manual.

The results section may consist 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 in narrative, 3) figures (graphs, diagrams, pictures), and 4) tables. The text of your results section should clearly ***describe*** what was found, and not require the reader to interpret data from figures and tables. Generally, results clearly *summarize* and describe trends in the data and observations obtained in the study. All statements must be supported with reference to data. All figures and tables included in your paper must be cited in the textual description of your results. Most importantly, the results section should be free of *interpretation* of the data (interpretation belongs in the discussion section). Once again, use past tense as this section describes what you found.

When reporting quantitative resuls, be sure to include both a measure of central tendency (e.g. average or median) and a measure of variability (e.g. range or standard error). Means (averages) should always be followed by an indication of variability around that mean such as the standard error, the units, and the number of replicate data points used to determine the mean. Follow the example: (25.4 ± 2.7 mm, n = 5). If you need to include actual raw data sheets, refer to them and attach them as an appendix to the paper.

Combine statements about the significance of differences examined by statistical tests with a precise indication of the test used and the probability level chosen. For example "males are significantly taller than females (t-test; $t = 4.5$; $d.f. = 12$; $P < 0.01$)". Null hypotheses are essential to understanding inferential statistics, but written reports usually *do not* mention them. Stating that you used a statistical test in your methods and the results of that test in your results implies that you were testing a null hypothesis.

Summaries of results may be presented as **tables** (including tabulated data and lists) or **figures** (including graphs, charts, photographs, sketches, maps, and other illustrations). Tables and figures may be embedded in your text, or it is often easier to put them on individual sheets either inserted in the page after they are referred to or all attached at the end of the report.

Tables and figures (see examples that follow) typically present *summaries* of data, not all the raw data points. Sketches are considered "figures" and should be accompanied by magnification if a microscope is used. Both tables and figures should have an **informative caption** containing the word "Figure" or "Table" followed by the figure or table number in the order referred to in the written portion of your results, and then be followed by a descriptive title. This "title" is a statement that explains the content (but not trends or results) of the figure or table clear enough so they "stand alone" without needing reference to the written portion of your results section. Table captions are always placed above a table, while figure captions are always placed below a graph, picture, or sketch.

Example of a table summarizing data from a study of fish schooling behavior:

Table 1. Time in minutes (mean ± SE) spent by bluegill test fish (n=10) in different areas of the tank. In the experimental treatment, area 1 had 6 conspecifics (bluegills), while area 2 had 6 heterospecifics (fathead minnows). In the control treatment, 6 conspecifics were in both area 1 and area 2.

	Minutes in Area		
	Area 1	No Fish	Area 2
Experimental	8.97 ± 1.0	1.87 ± 0.8	1.15 ± 0.3
Control	4.20 ± 1.54	4.04 ± 1.28	3.76 ± 1.09

Both Table 1 and Figure 1 illustrate summaries of the same data. Unless instructed otherwise, do not include your raw data, or put the same data summary in both a table and a figure. Choose the

method that is most effective in showing the information. Also, notice the graph is not labeled "Graph 1", but "Figure 1".

Example of a graph summarizing data from a study of fish schooling behavior:

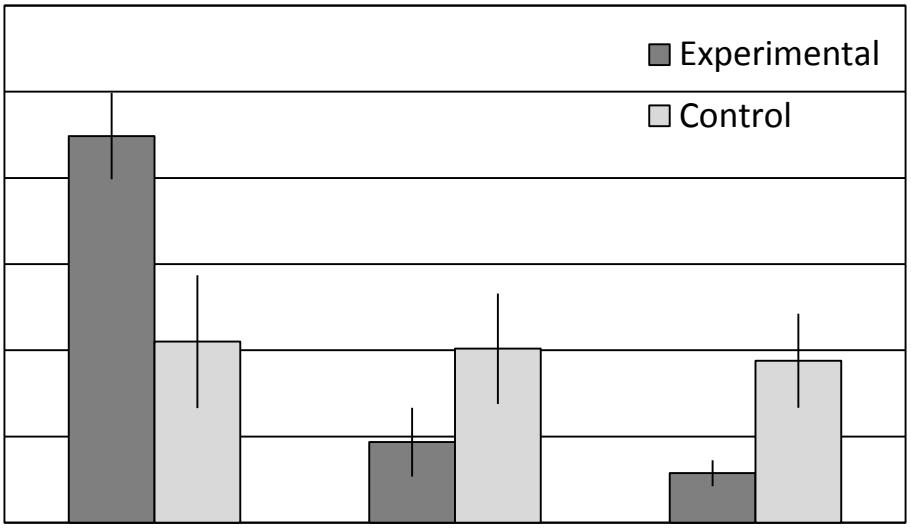

Figure 1. Amount of time in minutes (mean ± SE) spent by bluegill test fish (n=10) in different areas of the tank. In the experimental treatment, area 1 had 6 conspecifics (bluegills), while area 2 had 6 heterospecifics (fathead minnows). In the control treatment, 6 conspecifics were in both area 1 and area 2.

In the text, describe trends revealed in all figures and tables by number. For example, your text might read: "Bluegills spent approximately eight times longer schooling with bluegills than fathead minnows (Figure 1)." Tables and figures should be numbered separately and consecutively as referred to throughout the paper (Table 1, Figure 1, Figure 2, Table 2, Figure 3, etc).

DISCUSSION

The discussion section is your chance to interpret your results and put them into context regarding your original objectives or experimental question. The discussion should also relate your findings to the present state of knowledge (cite sources) and possible future needs for research. Make sure this is genuinely interpretive (explains your results, i.e. answering *why*?), and not just a restatement of the introduction or results sections. You might want to start with restating your experimental question or predictions and how your results did or did not confirm your question or prediction. Are there any possible alternative explanations for your results? It is very important that each conclusion that you make is justified by results of your experiment(s) and that you make the connection between the results and your conclusions. Any statements of fact or opinion must be supported by references to the literature, to your data, or specific examples.

You should discuss the broader significance of your results, i.e. do they have implications for our understanding of the organism(s) studied or can they be applied to problems such as public health or maintaining biodiversity? You may also wish to suggest additional hypotheses that could be tested.

Your discussion may include problems or limitations you encountered with experimental design, data collection or analysis. It should address any unusual or unexpected findings logically. When appropriate, identify any possible sources of error, and how such difficulties might be avoided.

As in other sections, when discussing your data and comparing it with previous studies, you must cite or acknowledge all outside sources of information.

LITERATURE CITED

In scientific writing, you take ideas and conclusions from other work to provide background information and to support your work. The sources of these ideas must be acknowledged with citations using the "author, date" method (see "Citing references in the text" below). In scientific writing you put these ideas *in your own words* and *do not use quotes*. Full reference information of only those references cited in your paper are listed in the Literature Cited section. This is an alphabetical list by author and year of all printed materials referred to in your report. Items you read but did not cite in the text of your report should *not* be included. When putting together your literature cited section, the following author/year format from the Council for Biological Editors (CBE) style manual should be used:

Citations from scientific research journals (by one, two, or three or more authors):

Eckblad, J.W. 1991. How many samples should be taken? *BioScience* 41: 346-348.

(this format includes the author, date, title of an article in the journal BioScience. The volume is 41 and the page numbers 346-348)

Larsen, K.J. and T.W. Work. 2003. Differences in ground beetles of original and reconstructed tallgrass prairies in northeastern Iowa, USA, an impact of 3-year spring burn cycles. *Journal of Insect Conservation* 7: 153-166.

Juneau, A., M. Kaehler, E. Christensen, C. Schad, A. Zinsmeister, J. Lust, C. Hanson, and G. Dewald. 1998. Detection of RB1 deletions by fluorescence *in situ* hybridization in malignant hematologic disorders. *Cancer Genetics Cytogenetics* 103: 117-123.

(note that the initials of all secondary authors are now placed ahead of their last name)

To cite a *book*:

Southwood, T.R.E. 1984. *Ecological Methods with Particular Reference to the Study of Insect Populations*, second edition. Chapman & Hall, New York.

To cite an *article in an edited volume* (book):

Loreau, M. 1986. Niche differentiation and community organization in forest carabid beetles, pp. 465-487. In: *Carabid Beetles, their Adaptations and Dynamics,* P.J. den Boer, M. Luff, D. Mossakowski & F. Weber (eds). Gustav Fisher, Stuttgart, Germany.

Citing References in the text

When references are cited in your lab report, the proper form for citations depends on the context. For example: "This response to lowered temperature is well known (Campbell *et al.*, 2008)"..., or ... "Sample size may need to be increased by a factor of four in order to double the accuracy of the mean (Eckblad, 1991)"; or "cells were tagged with fluorescent probe using the methods of Juneau and colleagues (Juneau *et al*., 1998)". If two authors are cited, both names should be listed: "(Larsen and Work, 2003)". If there are more than two authors, only the first author's name is listed, followed by "*et al*." which means "and others" "(Juneau *et al*., 1998)". Please note that within your paper, you *do not* include the quotes used above as examples.

Locating Appropriate References

Textbooks and review articles are an excellent starting place for developing background information for your investigations. Textbooks and review articles will often have lists of articles and other references that may be helpful. Textbooks, review articles, and articles from popular science magazines are **secondary references**, which provide a summary and interpretation of a particular body of research. These do not provide original data and may not be peer-reviewed.

Scientific papers that report original research are considered **primary references**. Primary references are journal articles that have been peer-reviewed by other scientists and journal editors. During peer-review, other scientists examine the experimental methods, results, and interpretation to

determine if an article has met the standards for publication. While not perfect, peer-review helps to maintain quality in science. In addition to articles in journals, primary references include conference papers, dissertations, and technical reports. Many scientific journals are available in full-text version online; these are still primary references as long as they have been peer-reviewed.

To find journal articles, the best place to go is the Preus Library. For books, search the library catalog. For journal articles and magazines, use one of the article and information databases, such as Biological Abstracts, AGRICOLA, BioOne, JSTOR, MEDLINE, PubMed, and many others. You can find these on the Preus Library website.

Citation of Websites from the Internet:

The internet can provide access to online references, resources and databases. These search tools provide access to a wide range of published papers, some of which may be available online as full-text journals. These papers are acceptable resources, as they have gone through the extensive review process. In scientific writing, citations of information from websites are typically limited to peer-reviewed materials that are also available in print versions (e.g. journals like *Science* that are published both in hard copy and on-line). Cite these articles using the "hard copy" information as if you had the journal in your hands, even if you accessed the article online.

However, the internet includes numerous websites with material that has not been critically reviewed (such as Wikipedia). These websites are not usually acceptable references. Note that government websites are not peer-reviewed, but usually are considered high quality and are acceptable.

If you need to cite a website be sure to evaluate these sites critically and realize that we may not accept these websites as references. Below is a sample citation of a website (from the U.S. Forest Service) appropriate for inclusion in a literature cited section.

Burns, R.M. and B.H. Honkala. 1990. *Silvics of North America*. <http://na.fs.fed.us/spfo/pubs/silvics_manual/table_of_contents.htm>. Accessed 15 September 2009.

In this example, the authors are "R.M. Burns and B.H. Honkala", "1990" is the date of the publication, and this may often be found at the bottom of the home page. "Silvics of North America" is the title of the article – basically a description of the website, then comes the complete Internet address enclosed in brackets "<" and ">", and finally the date you accessed the website.

FINAL THOUGHTS

If you're unsure how your paper should be put assembled, ask your instructor! Scientific writing involves lots of peer review and constructive criticism. Take comments as opportunities, not personal attacks.

BIBLIOGRAPHY

Council of Biology Editors. 1999. *Scientific Style and Format: The CBE Manual for Authors, Editors, and Publishers*, 6th Edition. Cambridge University Press, Chicago, IL.

Cox, G.W. 1990. *Laboratory Manual of General Ecology*, sixth edition. Wm. C. Brown Publishers, Dubuque, Iowa.

McMillan, V.E. 2005. *Writing papers in the biological sciences, 4th ed.* Bedford/St. Martin's, Boston, MA.