EFFECTIVE SCIENTIFIC WRITING

Effective scientific writing is a difficult, time-consuming activity that few people are *naturally* good at (even professors work hard to refine and improve their scientific writing skills). Learning to recognize and produce effective scientific prose represents one of the most significant challenges of a student's academic career. The Biology Department acknowledges this challenge and remains strongly committed to the improvement of scientific writing skills. The information provided here highlights the department's goals and expectations for science writing in our classes.

I. The goals of effective scientific writing

Scientists generally communicate with one another via written reports (called "scientific papers"). These are published in professional magazines or "journals" that are carefully reviewed by other scientists before they are published. Much of our collective scientific knowledge resides within these papers, and learning to effectively write and interpret scientific literature are both major components of science education.

Within a scientific paper, researchers typically explain four basic things:

1) What they did

2) Why they did it

3) What they found out

4) What they think it all means.

Providing this information, in a context of ***critical thinking*** and ***synthesis*** (putting concepts and findings together), is the primary goal of scientific writing. Critical thinking incorporates theory, data, and logic to produce a cogent opinion about a specific scientific undertaking. The author's synthesis of these ideas should balance the accuracy, value, and significance of different possible interpretations of the results.

Note that the goals of a scientific paper differ from the goals of the traditional "lab report" assignment from many chemistry or physics courses. A lab report usually describes an experiment, and focuses on 1) clear description of the methods and data, and 2) arriving at the "correct" result. In a scientific paper, clear descriptions of methods and data are also critical, but there is no "correct" result; instead, the discussion must contain a careful, informed, and balanced evaluation of the data in the context of prior studies.

II. The basic principles for good scientific writing

Good writing in science is not significantly different from good writing in other fields. The rules of good grammar, spelling, punctuation, and style still apply. Scientific communication demands precise, unambiguous language, as well as clear expression and logical organization.

Write to convey understanding, not to impress. Use simple language whenever possible. Eliminate irrelevant information, no matter how interesting you think it is, or how hard you worked to gather it. It is a distraction.

Organization is critical. Develop ideas within a paper as a series of strong, logically-connected paragraphs. Well-written paragraphs stand alone, yet provide context to information that both precedes and follows. Many scientific papers begin with broad themes that become progressively more focused with each subsequent paragraph. Sometimes it is easier to compose that first paragraph only after writing the rest of a paper or report. See the section on organizing ideas.

III. The format of a scientific report

Scientific reports differ from reports or papers in literature or history. Scientific writing demands certain conventions and authors must follow strict guidelines. Although this rigid structure may seem cumbersome and arbitrary at first, these conventions promote precise, unambiguous communication.

Unless stated otherwise, the Biology Department at Lewis and Clark expects students to recognize and apply this format to all writing efforts in our courses.

There are eight basic sections to a scientific report:

1) Title and Author(s)
2) Introduction
3) Methods
4) Results
5) Discussion
6) Acknowledgments
7) Literature Cited
8) Tables, Figures, and Equations

Except for the Title, all sections of a scientific report should be headed with the appropriate name (Methods, Results, etc....)

1) Title: A name for your report and a list of authors.
An effective title is brief, but informative; a concise description what a report is about. Center the title at the top of the first page or on a separate cover page. Include the scientific name (Genus and species) of any organisms mentioned within the title.

Beneath the title, give the names of the study's authors, either alphabetically, or in some order determined by who did the most work. Follow the authors' names with the name of the institution(s) where the work was done.

2) Introduction: A statement of purpose; what hypotheses were addressed and why is this an interesting problem?
Introductions put a scientific report in context. Why was a study done? What questions were asked and why is this interesting? The introduction focuses a reader's attention upon specific hypotheses and relevant background; have other scientists studied similar questions and how does the present study relate to this past work? Include brief descriptions of this earlier work and its relation to your study.

Successful introductions are usually several paragraphs long and follow a basic organization that narrows a reader's attention onto specific issues or questions. Most begin with a general paragraph that introduces the issues being studied. Succeeding paragraphs provide increasing detail and focus. The concluding paragraph often describes the specific question or hypothesis addressed by the authors.

3) Methods: A description of what was done - The "how", "where", and "when" of a study.
An effective methods section provides sufficient detail that others could repeat the study at a later time. Thus, methods must be described concisely and completely. Describe the measurement of **all** relevant variables and how they were monitored, including times and dates. If you were working out of doors, describe the environment and environmental conditions at the time of data collection. Include the Latin and common names of any study organisms. Be sure to include the number of samples collected, including descriptions of study plots, replicates, etc.

When working from a lab manual, **DO NOT simply recopy the protocol from the lab manual; this is a waste of time.** Instead, refer to the parts of the manual that provide a complete description of the method. Be sure to include any modifications you made to the published procedure**.** For example:

"We followed the methods of our laboratory manual (Bierzychudek et al. 1998), on pages x to y, with the following exception..." Be sure to include the laboratory manual in the Literature Cited section at the end of your paper. (Refer to the **Literature Cited** section of this document for further information.)

Remember, as a description of what has already been done, methods should be written in the past tense.

4) Results: a summary of what was recorded during the study.
The "Results" section describes the various data obtained during a study. In general, do not present these data in their "raw" form (i.e., the way they were originally recorded into a laboratory/field notebook... although see below*). Instead, summarize results in a condensed form that allows a reader to easily digest and interpret the findings. This can be accomplished in three basic ways: 1) within the text; 2) as a part of a figure; or 3) within a table. For example, when comparing groups of observations, means and standard deviations could be reported directly within the text. Alternatively, a figure showing how means (plotted on the y-axis) varied by group (along the x-axis) could show the same thing. So could a table that listed relevant statistics by group.

The effectiveness of a Results section depends largely upon the effort put into organizing the raw data into tables and figures. Strive to present results in a manner that effectively and efficiently communicates their meaning and importance. Relating results to the specific questions or hypotheses presented in the introduction can improve the cohesiveness of a report. For example, "As we predicted, the trees covered with ivy tended to have less moss on their trunks than the trees without ivy.". Follow this general statement with more specific, quantitative information. For example, "Trees without ivy had an average of 45.7 square millimeters of moss (range: 25 to 53), while trees with ivy had an average of ....". Remember that scientists always analyze data quantitatively. If a rate increased over time, describe the extent of the increase. Did it double? Triple? Finally, avoid lengthy explanations of why a result does or does not fit with expectations. Save that for the discussion.

Some thoughts about figures:
When presenting data in tabular or graphical form, provide an adequate legend or caption; explanatory text that draws the readers' attention to interesting or important trends. Figures and tables produced on a computer will typically have better visual impact than those drawn by hand. Software programs such as Excel and Statview provide good graphing abilities. Both are supported by the College. Figures and tables done by hand must be clearly and neatly drawn and lettered. Although most word processing software now allows the integration of text, tables, and figures, placing graphics or tables on separate pages at the end of a paper is also acceptable.

Think about what you want to show the reader **before** you create a figure. Just because a computer program generates a pretty graphic doesn't mean that it conveys meaning. Avoid three-dimensional graphics -- these figures rely on a non-planar sense of spatial perspective and do not allow for accurate presentation or interpretation of results.

* Some professors may require a table of raw data at the end of a report or paper so as to highlight potential problems or sources of error within a study. Such a table is generally not included in a professional paper, but in the learning process, it is often helpful.

5) Discussion
In this section, authors interpret their results. For this reason, the Discussion is perhaps the most vital part of a scientific report; it certainly requires the greatest amount of

thought. Thoughtful analyses reveal an understanding of the biological principles behind a study. Thus, explanations within a Discussion should be logical and based upon evidence. To provide a context for interpreting the results, Discussions often draw upon other sources of information,such as course lectures or outside reading.

Begin the Discussion with the most important observations/data and move to less central information. Evaluate the meaning of results and explain what conclusions you have drawn from them. If appropriate, discuss them in relation to other studies that have been done on the same subject. Above all, return to the question(s) you asked in the Introduction, and explain what answers you have arrived at.

If results seem unexpected or contradictory, point this out and try to devise an explanation that is at least reasonable (of course, until you test it, it is only speculation and should be identified as such). If you feel that a flaw in the design or execution of the experiment might account for your unexpected results, explain what this flaw is and how it would have influenced your results. *There is no reason to include a section, called "Sources of Error" (as you may be accustomed to doing in chemistry), unless you are aware of some major flaw in your methodology.* Be sure to make a distinction between conclusions that you are very sure about, and other conclusions that may be more tentative. Do this by means of the language you choose. ("We observed a decline in plant diversity as we got closer to the coal-generating plant. We suspect that this may be a result of increasing levels of particulate fallout, but since we did not measure particulate fall-out levels, we do not know for sure.")

Do not expect to write up your results in an hour. "Our experiment did not work" is not an interpretation; indeed, it's a misunderstanding. It implies that if you didn't get what you expected because of a problem with the experimental protocol. Alternatively, it may be that your expectations were incorrect. In fact you're not doing an experiment if you know the outcome before you do it; it's an exercise. It's okay (and common in science) to generate unexpected results. Remember, the purpose of science is to discover new information. This new information often allows us to see the world in new ways.

Scientists always think about the significance of their results. You may develop a further hypothesis as a result of analyzing your data. The Discussion is the place to state that hypothesis and to suggest new experiments that you could do to test it. This section requires that you take some intellectual risks, to propose some ideas. You do not have to be right; often there is no one right answer. You must only be internally consistent, and logical in your thinking about the problem.

Professors often weigh the quality of a Discussion section most heavily when assigning a grade. A well-written discussion reveals the degree of planning that went into observations and experiments were logically planned, whether the authors understood what they were doing, and whether you can draw rational inferences from your data--all skills that scientists (and anyone who thinks clearly) will need.

6) Acknowledgments: Who helped and with what.

In this brief section of one or a few sentences, authors acknowledge any and all help they received during the study's planning, execution, analysis, and write-up. This may include a variety of people (e.g., "We are grateful to the members of group 4 for their suggestions about improving our study; in particular, Liz suggested that we double our sample size, which turned out to be very important. Thanks to our TA Ricky for his advice about graphing our results, to Janet for loaning us her fishnet, and to Jason for the chocolate-chip cookies he baked us!"). Any sources of monetary or logistical support are also noted in this section. For students, the Acknowledgments section illustrates two important factors. First, it is perfectly allowable, and indeed a good idea, to brainstorm with others about your project at its different stages, because such brainstorming can stimulate lots of good ideas. Second, never misrepresent ideas you get from others as your own; always give credit to the sources of those ideas.

7) Literature Cited: A list of relevant references.

This section of a paper lists, in a specific format, the sources of information referred to in the paper itself. It is a common mistake to include here all the references that you might have looked at while planning, performing, and writing up the study; that's not necessary. Only if a specific piece of information in your report came directly from a reference should you cite that reference.

8) Tables, Figures, and Equations.

The scientific paper format also includes Tables, Figures, and Equations. Each table, figure, or equation must be numbered and referenced in the text. Each table and figure must have a legend. A legend consists of text describing what the figure or table shows. The legend should be detailed enough that the figure or table makes sense if read separately from the paper. Table legend placement is above the table; figure legend placement is below the figure.

An example of a figure with legend:

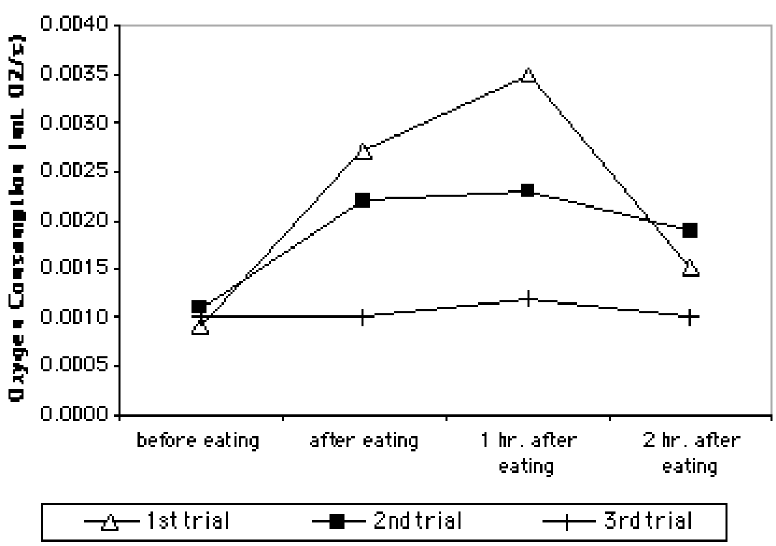

Fig. 3 Resting Metabolic Rate (mL O2 s-1) in an individual garter snake (*Thamnophis sirtalis*) before and after feeding. Triangle, square, and cross symbols represent consecutive trials. Each trial followed 2 to 3 days of starvation. Note how the post-feeding response decreases in intensity over the course of the experiment.

The scientific paper format does not include "Graphs", "Plots", etc."

IV. Organizing a scientific paper

Good writing does not just happen. A good scientific paper, as with any written communication, requires forethought and organization. Prepare an outline *before* you begin to write. Outlines often highlight how ideas, concepts, and background information can logically be organized into paragraphs. Remember, the introduction sets the tone for all that follows, so guide the reader by explicitly stating hypotheses and goals (e.g., "I will argue that 1) xxxxxx, 2) xxxxxx; and therefore 3) xxxxxx"). Let these ideas provide the logical structure to remaining sections of a paper and refer back to them within the discussion.

Support all statements, either with data or reference to published, peer-reviewed, scientific evidence from the primary literature. Web sites are ***not*** examples of peer-reviewed material (though many web sites contain valuable and accurate information). Statements that represent speculation or arbitrary judgment on the part of the author should be acknowledged as such.

Make sure that your paper concludes by fulfilling your goals! You might suggest future directions or unsolved questions.

When finished, make sure to trace the logic of your arguments from introduction to conclusion -use formal logic if applicable. Many papers lack logically cohesive arguments or are contradictory; don't let this happen to you!

Build a strong first paragraph. Sometimes it is easier to compose that first paragraph only after writing the rest of a paper. Make clear exactly what you are setting out to do. Every paragraph should follow logically from the preceding one. State your case and build it carefully, providing supporting evidence where necessary.

V. Preparing a scientific paper and time management

Time management. The effort needed to write a scientific paper or report often surprises students - simply put, it's a lot of work and students must plan accordingly. To allow for sufficient time to craft a written lab report or scientific paper, students need to begin thinking about their results and conclusions well in advance of the actual due date. Many of our labs provide class time to work on the analysis and interpretation of data. Also use this time to discuss how these findings will be organized and presented. Investment of time and intellectual effort at this stage of a scientific paper improves both writing and thinking skills. Don't hesitate to contact your professor if problems or questions arise.

Drafts. Do not hand in an unreviewed paper; any final version of a paper should have been read and edited by at least one person other than the author. Revisions should build off the suggestions of reviewers. If a reviewer doesn't understand something, it is incumbent upon the author to enhance clarity. The Department of Biology encourages students to submit preliminary drafts of a paper well before the actual due date. In some classes this procedure is mandatory. Instructors can use drafts to evaluate what a student did and provide important feedback on how results should be presented. The reworking of a draft provides valuable practice that invariably results in a superior end product. To this end, students should aspire towards quality scientific writing in all their assignments, even preliminary drafts.

Proofreading. Make sure to edit carefully. Use a spell-checker if you have a computer. Strive to eliminate unnecessary or redundant sections. Add more to sections that clarify key points. (This is a normal part of the evolution of any paper). It often helps to proofread a manuscript printed on paper rather than one that is simply displayed on a computer monitor.

VI. Resources to improve your writing

Faculty and fellow students: Feedback from professors, teaching assistants, and fellow students represents one of the best ways to learn how to write better. *Don't be afraid to ask your professors to help guide your development as a scientific communicator.*

The Writing Center offers various forms of writing instruction and tutoring. They recognize the special needs of scientific writing and are focused on helping students improve.

Selected texts: These books also provide many useful insights on the art of scientific writing,

R. Barrass 1978. *Scientists Must Write*. John Wiley and Sons, New York.
C. S. Loban and M. Schefter 1992. *Successful Lab Reports: A Manual for Science Students*. Cambridge University Press.
V. E. McMillan 1988. *Writing Papers in the Biological Sciences*. St Martin's Press, New York.
J. A. Pechenik 1997. *A Short Guide to Writing About Biology*. Addison-Wesley Pub Co.

VII. Style Guidelines - a few helpful hints for a scientific communication (with examples generously provided by Lewis and Clark students)

Always strive to write for a "professional" tone no matter whether your expected audience includes fellow students, professors, or researchers outside the College. Avoid writing about the "assignment" or "the class".

In general, discuss concepts and data, not "papers", "articles", or authors. Don't just summarize the papers you read. Scientific papers are not "book reports". Avoid quotations to minimize this problem (see below).

Avoid a passive voice in your writing. Use of passive verbs (is, was, has, etc...) represents an outdated, bland style of scientific writing. Active verbs convey information concisely and with greater impact. Thus, strive for an "active voice" when writing scientific papers. Most professional biology journals expect the use of an active voice. For example:
"Real life" examples of a "passive" voice (passive verbs in italics) with the same ideas rewritten in an "active" voice below (active verb in red).

> a) "There *were* no bees concentrated at the top three air holes as previously observed rather they *were* clustered around the air-hole screens between the upper and middle honeycomb". (29 words)
>
> a') "In contrast to their previous concentration near the upper three airholes, honeybees clustered around the screened vents between the upper and middle honeycomb". (23 words)
>
> b) "The objective of this observational trip *was* to determine the methods one *would* use to quantify the patterns of dispersion and association among animals in nature". (26 words)
>
> b') "We sought to develop methods that quantified natural patterns of animal dispersion and association". (14 words)

Avoid excessive quotation. Many professional scientists avoid quotes altogether. Instead, write others' ideas and findings in your own words.... just be sure to cite the sources every time you do!

> With quote: More investigations are needed to understand acclimation, as Verde and McCloskey (1998) state: "Such seasonally dependent physiological effects emphasize the requirement for seasonal investigations of algal-cnidarian symbioses in order to comprehend the ecological physiology and photobiology of the symbiotic association on an annual cycle."
>
> Without: Observations of seasonal shifts in algal physiology within tropical habitats highlight the need for studies of seasonal acclimation within temperate algal-cnidarian symbioses (Verde & McCloskey 1998).

Avoid overly verbose or pedantic style.

> Wordy: It has been discovered that vampire bats exhibit reciprocal altruism (Wilkenson, 1984).
>
> Better: Vampire bats exhibit reciprocal altruism (Wilkenson, 1984).

Wordy: On February 29th, our laboratory group for Animal Behavior went on an observational excursion to a local pond to collect data on waterfowl behavior.

Better: On February 29th I observed the behavior of waterfowl at a local pond.

Avoid "touchy-feely" writing that relies too much on your personal experiences or denotes feeling to the study organism.

Example: "Elephants seem to be attracted to other elephants and when the ecological conditions allow, they prefer being in large social groups".

Better: "When ecological conditions permit, elephants typically occur in large social groups".

Avoid the use of slang or clichés:

Unacceptable: "Making the lake into a grid would make it possible to examine if the Buffleheads prefer to hang out on one side of the lake".

Better: "I propose to quantify the spatial distribution of Buffleheads on the lake by establishing a grid.

Make the paper readable: If you have a computer with a choice of typefaces (fonts), please choose one that is large enough (at least 12 point) and easy to read (e.g. Times).

Use section headings and subheadings to orient the reader. Don't be afraid to repeat these in subsequent sections of a paper. Italics and indentations can help.

Avoid common mistakes in the use of a correct word: Talk to your professors if you have questions about the following:

Affect vs. effect.
Experiment vs. observation.
The use of "data" (They **ARE** plural).
Less/fewer and amount/number; use the proper term when referring to continuous vs. discrete variables.