Writing Scientific Papers In Biology

In most courses in the Biology Department, you will be asked to write papers that describe projects you have performed in the laboratory. Like papers in non-science courses, we expect them to be well-written, creative and thoughtful. Unlike papers in other courses, we expect them to conform to a format common to biological journals, which is described below. It is critical that you understand the details of this format and particularly that you do NOT confuse these papers with "lab reports" required by other science courses at the University of Minnesota.

The following describes how your paper should be organized. However, this doesn't mean that you should write the paper in this order! We suggest writing the paper in this order: (1) Materials and Methods (2) Results, (3) Discussion, (4) Introduction and (5) Title.

In each section below are listed some "serious flaws." Be aware. They cause a significant penalty when your paper is being graded.

Title

The title tells *what* the paper is about. Under it should be your name and "professional address," which in this case is the specific lecture and laboratory sections in which you are enrolled. For this course, it is sufficient to put this at the top of the first page, although other professors may ask you to have a separate title page (We don't in order to save paper).

A title should be informative, specific and concise. Since you are not writing a murder mystery, it is all right to tell the "ending" in the title. It is often this information that helps a reader decide if the paper is something he/she wants to read. Here are few examples that illustrate this:

- **Really Bad Title:** "Lab 2 - Plant phenotypes " This tells the reader nothing except that the second lab of the semester involved looking at plant phenotypes! Although it may distinguish this project from others in this course, it would not help someone outside of class understand what the paper is about. This is a fatal flaw.
- **Better, but not very good:** "Growth and phenotypic variation in the golden rod, *Solidago gigantea".* This gives specific information about the organism and type of measurement, but still does not inform the reader about the problem being investigated. Why do you want to measure variation in growth of golden rods?
- **Good:** *"Solidago gigantea* growth shows lower heritability than morphological characters " The title indicates that the objective was to compare levels of heritability in different characters of a goldenrod, and even what the result was!

Introduction

The introduction should briefly explain *why* the research was done, relating this research to other relevant work and giving the reasons for choosing the hypothesis to be tested. A good way to organize the introduction is to begin with the general and proceed to the specific. Assume that the reader is at least moderately familiar with the general subject of the paper. However, unless you are studying a model organism (e.g., *Drosophila, Arabadopsis, E. coli* etc.), it is important to describe enough aspects of its natural history that the reader can appreciate why it was chosen for the study. A good introduction will mention the major issues that will be considered in the Discussion section, and that's why we suggest writing it after finishing the other sections.

Fatal flaw: Don't start the paper with the phrase: "The goal of this experiment was…" This is not a general statement about the subject.

Materials and Methods

This section should carefully explain *how* the research was done. Organize the sections logically, using subheadings if there are more than several paragraphs. Include all materials used, the exact conditions employed, and how you gathered the data. You may cite the lab manual (or another source) for a common technique. Here's an example:

- **Bad:** "We measured growth rates and wrote down the data." How did you measure growth rates? You don't need to tell the reader that you recorded the data or entered it into the computer.
- **Good:** "We estimated yeast density according to directions given in the **Sources of Genetic Variation** lab handout (Brown and Eckhart, 1997)."

If you develop your own technique, you should explain it in sufficient detail that another person could replicate your work. Tell exactly what materials you used (composition of solutions, media, etc.) and describe the procedures precisely. Commonly used statistical tests generally need no explanation or citation.

Fatal flaw: Don't present your materials and methods as a list. Write in complete sentences and organized paragraphs.

Results

The results section should summarize, *but not interpret*, the results obtained. One good way to approach the writing of the Results section is to develop a set of questions about the data you gathered. Don't use any questions that begin with "Why" -- these necessarily involve interpretation, so they should be addressed in the Discussion section. Write your Results section by answering each of these questions in a logical order. Refer to Figures and Tables as you describe the results.

Figures and tables frequently will help the reader to understand more easily than a written description. They should not duplicate text, and text should only tell the reader the major points to be noted on the graphs or tables (that is, should tell the reader what you think is particularly important about the data presented). Obviously the same data should not be presented in two different forms, so decide which form helps you tell your reader what you want him/her to know. Graphs of any kind, as well as other pictorial materials, are referred to as "Figures" in the text, and are numbered. Tables are called "Tables" in the text, and are numbered separately from figures. Each figure or table should be on a separate page. They may either follow the first reference to them in the text, or all may be collected at the end of the paper. All figures and tables must be "called out" or referred to before they are explained in the text.

- **Bad example:** "The results are shown in Graph l." This is not a summary of the results, and the graphs should be referred to as "Figures." This is a fatal flaw.
- **Another bad example:** "Growth rates under low fertilizer had an average of 3.2 g with a 95% confidence interval of ± 1.4 g, and growth rates under high fertilizer treatment had an average of 6.5 g with a 95% confidence interval of ± 1.0 g (see Figure 1). Since the intervals do not overlap, they are significantly different at the 0.05 level." The text here repeats specific information that is also shown in the figure -- since the figure conveys this information more efficiently it's not necessary to repeat it in the text. It is also not necessary to explain why non-overlapping confidence intervals indicate a significant difference, since this is a commonly used statistical test.
- **Good example:** "We found that higher levels of fertilizer resulted in significantly larger growth rates, as determined by the 95% confidence intervals (Figure I)."

<u>Graphs</u>

- Use a graph to illustrate a relationship or pattern in your data.
- Be sure that the type of graph you choose is appropriate for the type of data you wish to display. What assumptions are you making by using a particular type of graph? For example, a line graph with the points connected indicates that the variables are continuous over the range displayed.
- By convention, the independent variable (the one you manipulated) is on the X-axis and the dependent variable (the result of the manipulation) is on the Y-axis.
- The axes of a graph must have clear, concise labels. If there is more than one line or bar on the graph, each must be clearly identified.
- All figures must have clear and specific legends. A legend is usually written as an incomplete sentence with only the first word capitalized and should begin with "Figure 1. The . . ." If required for clarity, you may include several more sentences. It should be placed above or below the figure. **[Note for users of EXCEL:** In EXCEL's very nice "Chartwizard", a "legend" refers to the part of the graph that explains what various lines/colors refer to. Use the "Title" box in the Chartwizard to type in a figure legend.]

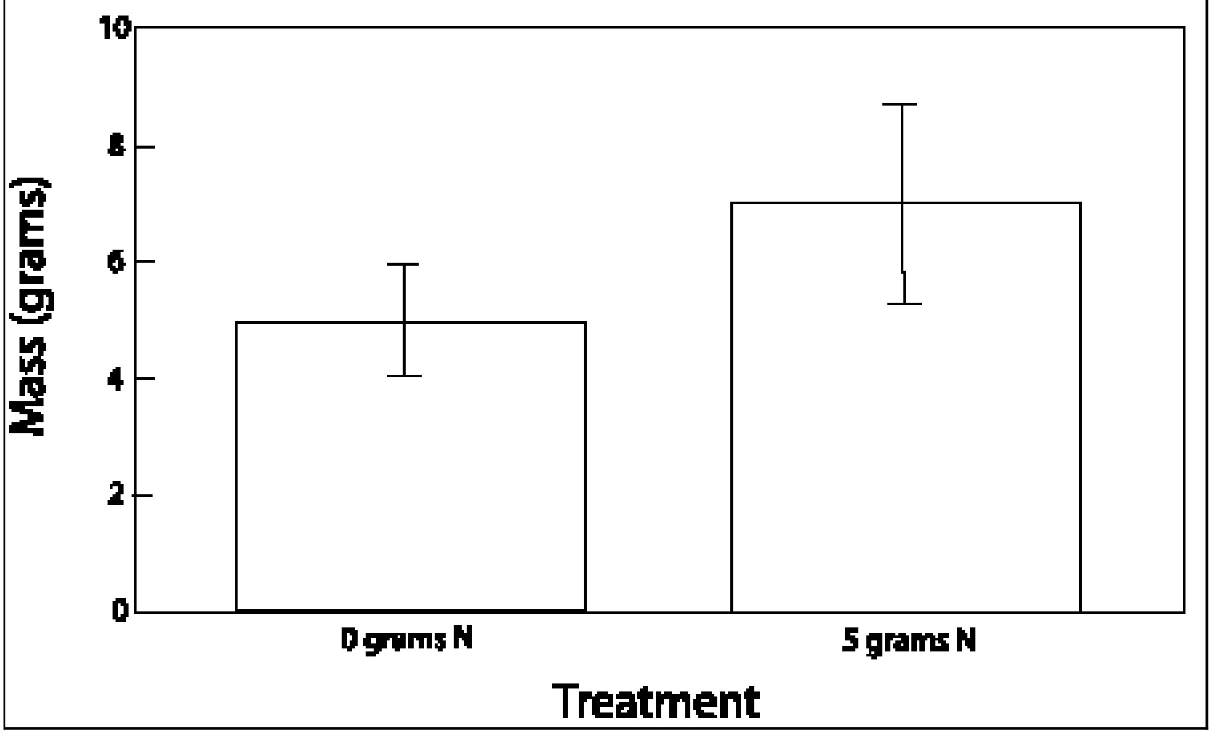
Imagine that you have done an experiment that compares growth rates of *Brassica* under two different fertilizer treatments. At the top of the next page is an example of a BAD GRAPH:

This graph makes poor use of space (note the big empty area). More seriously, the reader can't tell from the figure whether the bars are mean values, and whether the difference between them is significant -- there needs to be some indication of the variation within each treatment group, i.e., error bars. Note as well that the Y axis has no units and the figure legend is not explanatory. There is an improved version of this graph at the top of the next page.

Tables

- Tables are used to present *matrices of data. If* it is important to show a pattern or trend, use a graph instead of a table.
- **Do not present raw data and expect your reader to do the arithmetic before s/he can understand the contents of a table. Printouts of EXCEL worksheets with raw data are NOT acceptable tables! This is a** fatal flaw.
- Try to avoid large tables - no one will read through them. Perhaps the information can be presented better in several smaller tables.
- All tables must have legends that explain their contents sufficiently that they can stand alone (much like figures). It is sometimes appropriate to have footnotes for a table.

Figure 1. The effect of fertilizer on growth of *Brassica*. Means (n = 5) and 95% confidence intervals are shown.



Discussion

The discussion should *interpret* and *explain* the meaning of your results and usually proceeds from the specific to the general. Begin with a summary of your results in a sentence or two. Remind the reader of important trends, etc. Then relate your results to your own initial hypothesis, arguing for a particular interpretation of your data. Don't forget that "negative" results can be important too, since they may suggest that your hypothesis was incorrect (After all, it is just possible that you did everything perfectly!). Relate your results as well to other papers or published hypotheses if appropriate.

The discussion should end with a summary - the "take home lesson" that you want your reader to remember about your work. It may also raise further questions for study. *However, if you* end *the discussion with the phrase, "but of course more work needs to be done, " we will lower your grade!* Please let me know what *kind* of work would be most informative and why.

Acknowledgments

Acknowledgments are used to *thank* any persons who contributed any significant help during the study. Such contributions include, but are by no means limited to, help in experimental design, collection of data, preparation of graphs, drawings or the manuscript, critiquing a draft of the manuscript or in financial or physical support of the work. Your partners in a group project must certainly be acknowledged!

References

The references list only the papers or other publications that were *directly referred to* in your paper; they are not a bibliography. References should be cited in one of two ways in the text: (1) Mention the authors' names as part of your sentence followed by the year of publication in parentheses; (2) Place authors' names and the year of publication in parentheses following ideas or results from the study. See examples below:

(1) "Brown and Wilson (1992) performed a set of experiments demonstrating variability in host specialization . . . "

(2) A phylogenetic tree of the yucca moth family indicates the important role of host-plant association in the evolution of this group (Brown et al. 1994). "

The following are examples of how articles should appear in the References section). Articles should be listed in this section alphabetically according to the first author.

Journal article: Brown, J.M. and D.S. Wilson. 1992. Local specialization on sympatric hosts: phoretic mites on carrion beetles. Ecology 73:463-478.

Book: Brown, J.M. 1999. How I became rich in academia -- a fantasy. Harper and Row, New York, NY.

General Comments

- Biological editors recommend using the active, rather than the passive, voice in scientific reports. Thus, instead of writing, "The plants were measured. . . ", you should write, "We measured the plants . . ." **Note that this convention may not be true in other disciplines (e.g., chemistry).**
- Use the past tense when describing your experiment and its results. Use the present tense when discussing general properties of organisms.
- No hand-written papers accepted.
- All text must be double-spaced with 1 inch margins on all sides.
- Pages must be arranged in the correct sequence, numbered and stapled together.
- Bear in mind Johnson's comment on Milton's *Paradise Lost : "If* its length be not virtue, it hath no other." Every word costs money to print, so keep it as short as possible consistent with a good job.
- And finally, never apologize for lack of data; assume that you have done the best job possible!

(Adapted from *Writing Papers in the Biological Sciences* (1988) by Victoria E. McMillan, St. Martin's Press, N.Y. Grading scheme adapted from Bill Wirtz's handout for Biology 112, Pomona College)

Scientific Paper Writing Tips

Overall

1) Do not capitalize the names of elements (i.e. nitrogen).

2) Do not capitalize the common names of plants and animals, unless there is a proper noun in the name (i.e. white pine vs. Norway pine).

Methods

Describe your methods completely. Include number of treatments and number of replicates. Someone who has never heard of your study before should be able to use your methods section like a recipe if they want to replicate your experiment. Be sure to describe what statistics you used.

Results

1) Always indicate p-values in parentheses at the end of a sentence.

DO – The decomposition rate of maple leaves was significantly greater than that of pine needles ($p=0.01$).

DON'T – Because $p = 0.01$ we concluded that the decomposition rate of maple leaves was significantly greater than that of pine needles.

2) Describe how the mean varies between treatments, but put the actual mean in parentheses.

DO - Habitat type had a significant effect on the number of adult worms caught ($p=0.02$). A significantly greater number of worms were caught in deciduous forests with buckthorn (mean = 25 worms) than in deciduous forest without buckthorn (mean = 13 worms) or in coniferous forest (mean = 11 worms; $p< 0.02$).

DON'T - Our ANOVA had a p-value of 0.02, so we concluded that habitat type significantly affected the number of worms caught. We found an average of 25 worms in deciduous forest with buckthorn, 13 worms in deciduous forest without buckthorn and 11 worms in coniferous forest. A Tukey test showed that there were significantly more worms in the deciduous forest with buckthorn.

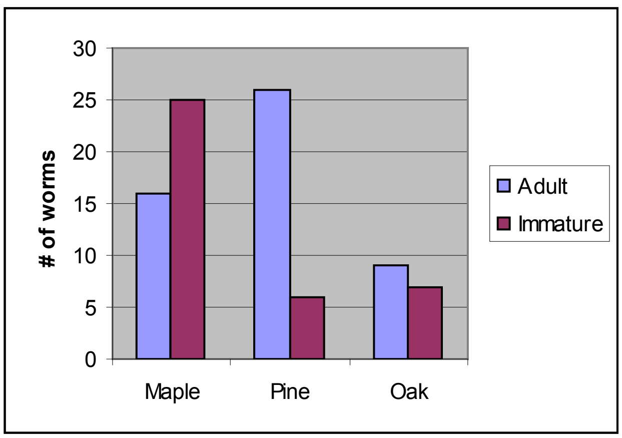
3) Always indicate that the reader should refer to a table or figure in parentheses at the end of a sentence.

DO – Canopy openness was significantly greater in deciduous forest than in conifer forest (p=0.04; Fig. 2).

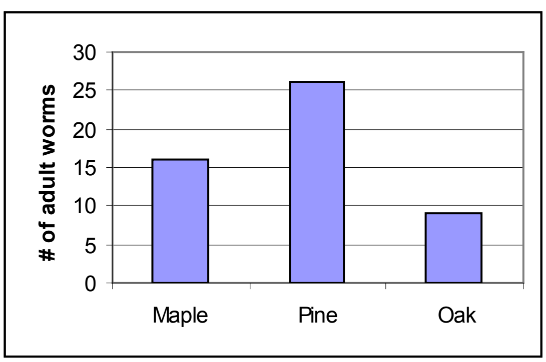
DON'T – Figure 2 shows that canopy openness was significantly greater in deciduous forest than in conifer forest.

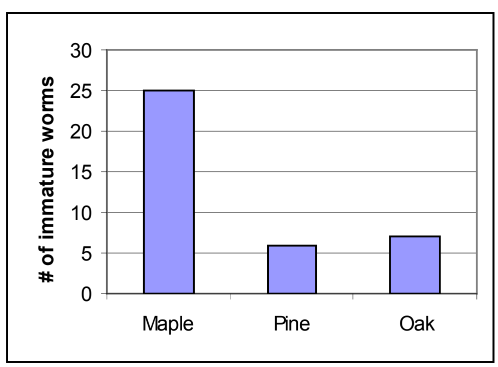
4) Do not have a graph for every analysis that you performed. Combine data in an informative summary graph.

DO –



DON'T -





5) Do not put titles on figures or tables. Figure and table legends should briefly describe what the figure and table are trying to show. Indicate statistical significance on figure or table and indicate what the p-value is in the legend.

DO:

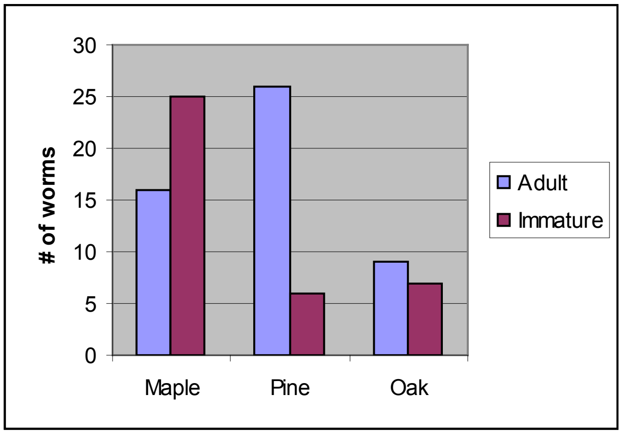


Fig. 2. Mean number of adult and immature worms found in each of three habitat types (n=5). $p < 0.05$.

DON'T

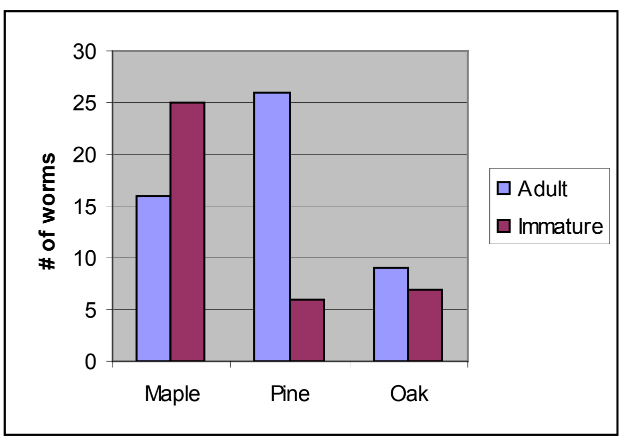


Fig.2. This figure shows the mean number of adult and immature worms found in maple, pine and oak habitats. There were statistically more adult worms found in the pine habitat and more immature worms found in the maple habitat. The p-values are less than 0.05.