

III. Communicating the Results of Scientific Investigations

While many people investigate the world for the pure love of discovery, science is only made complete when discoveries are communicated. Many scientists love to do this as well. In this section of the manual, we describe three ways scientists convey ideas to their colleagues: scientific papers, posters, and oral presentations. Each has distinct forms and conventions, although the similarities among them should also become clear. We describe how to approach each type of communication, their conventions, and our methods of evaluating them. As in all courses, it is important that you check your instructor's expectations.

The Scientific Paper

What is a scientific paper and why do we write them?

A scientific paper is a formal way for working scientists to report the results of original investigations in a public and permanent fashion. Papers appear as articles in scientific journals published in print and online. Due to the importance of this "primary literature" in informing new investigations, articles published in journals undergo rigorous peer review for clarity, accuracy and importance. We want you, as a working scientist, to understand this process and contribute to the primary literature through your own investigations.

General advice

Like papers in non-science courses, your scientific papers should be well written, creative, and thoughtful. The purpose of a scientific paper is similar to other academic writing. It is a narrative of your investigations and an argument about their meaning. In many ways, the principles of scientific writing are the same as academic writing in other disciplines:

Audience -- Knowledge of audience will help you decide what terms or ideas you need to define and how formal to make your language. Assume the audience consists of peers, i.e., unknown readers with a similar background in the subject matter as your classmates.

Brevity -- Scientific writing is often described as concise and non-ornamental. This does not mean it has to be boring.

Vigorous writing is concise. A sentence should contain no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts. This requires not that the writer make all his sentences short, or that he avoid all detail and treat his subjects only in outline, but that every word tell. (Strunk and White 1979)

Structure -- The structure of writing helps convey your narrative and arguments clearly. The *Advice to Authors* (below) discusses the purpose of specific sections of a scientific paper. However, the careful construction of your writing should be apparent at all levels: sections, paragraphs and sentences.

Conventions -- As in most disciplines, scientific papers need to conform to particular stylistic conventions; in journals these rules are given in the editors' *Advice to Authors* (see below). It is important to understand the similarities and differences in the conventions of biology and chemistry and to inquire about specific expectations and requirements of individual professors.

There are three aspects of scientific writing conventions that bear special mention:

Voice -- . Discuss the following passages with your instructor to make sure you understand the conventions and expectations for use of passive and active voice for papers for a particular class.

From Alley's (1996) *The Craft of Scientific Writing*:

Many scientists and engineers hold the misconception that scientific documents should be written *in the passive voice*. Not true. Because the purpose of scientific writing is to communicate (inform or persuade) as efficiently as possible, and because the most efficient way to communicate is through straightforward writing, you should use the most

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straightforward verbs available. Needless passive verbs slow your writing; they reduce your writing's efficiency. . . . Is passive voice wrong? No. Although the *active voice* ("The oscilloscope displayed the voltage") is stronger than the passive voice ("The voltage was displayed on the oscilloscope"), there are occasions when the passive voice is more natural. For instance,

On the second day of our wildebeest study, one of the calves wandered just a few yards from the herd and was attacked by wild dogs.

In this example, there is nothing wrong with the passive verb "was attacked" because the passive voice allows the emphasis to remain on the wildebeest calf, which is the focus of the paragraph. The key to choosing between an active and passive verb is to ask which form is more natural. . . .

Some passive voice arises in scientific writing because scientists cling to the misconception that they can never use the first person ("I" or "we"). . . . As long as the emphasis remains on your work and not you, there is nothing wrong with judicious use of the first person. . . . First, you should reserve the use of the first person for those occasional situations in which your role in the work is important – for instance, when you make an assumption. Second, you should avoid placing the first person (either "I" or "we") as the beginning word of a sentence, because that position receives heavy emphasis. Instead, have the first person follow an introductory adverb, infinitive phrase, or dependent clause.

From Day and Gastel's (2006) *How to Write and Publish a Scientific Paper*:

Let us now talk about *voice*. In any type of writing, the active voice is usually more precise and less wordy than is the passive voice. (This is not always true; if it were, we would have an Eleventh Commandment: "The passive voice should never be used.")

As noted in Chapter 11, the passive voice sometimes functions well in the Methods section. Elsewhere in the scientific paper, however, it rarely should be used.

Why, then, do scientists use so much passive voice? Perhaps this bad habit results from the erroneous idea that it is somehow impolite to use first-person pronouns. Because of this idea, the scientist commonly uses verbose (and imprecise) statements such as "It was found that" in preference to the short, unambiguous "I found."

Young scientists should renounce the false modesty of their predecessors. Do not be afraid to name the agent of the action in a sentence, even when it is "I" or "we." Once you get into the habit of saying "I found" you will also find that you tend to write "*S. aureus* produced lactate" rather than "Lactate was produced by *S. aureus*."

An example from the first paragraphs of Watson and Crick (1953):

We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey. They kindly made their manuscript available to us in advance of publication. Their model consists of three intertwined chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons:

(1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other.

(2) Some of the van der Waals distances appear to be too small. Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it. We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid.

Quotation -- Never use quotation without consulting your instructor. Quotation is extremely rare in scientific primary literature articles and used only when the author is trying highlight the *exact words* used by another investigator. Compare articles in biology and chemistry journals with those in the social sciences or humanities to appreciate how different these practices are between disciplines. Paraphrase your sources carefully, and cite your sources according to the conventions of the particular journal (see below). **Please remember, however, that this rule does not grant permission to use verbatim language from sources without quotation marks!** Your College Student Handbook contains excellent advice on how to paraphrase while maintaining academic honesty.

Honesty In Academic Work

A section of the Grinnell College Student Handbook ** is this the current language?

Paraphrase carefully: When you paraphrase—that is, when you put what a source says into your own words—you must not merely rearrange a few words from the source, but must recast the passage or sentence completely. In addition, you must specifically acknowledge any material that you have paraphrased or summarized, even when you have substantially reworded or rearranged it. It is not acceptable to explain similarities between your work and that of others by claiming that you read the source or sources long ago and have confused the phrases and ideas of the other author or authors with your own. Rule of thumb: when in doubt, cite.

Cite ideas and data: You are also obliged to acknowledge, whether in an in-text citation or a footnote, any idea you have borrowed from another person or source. Scholars, researchers and writers often engage in intense discussions, with each speaker confirming or modifying some aspect of another's thought. Given these circumstances, it's often difficult to credit the source for any given idea. However, such acknowledgment is part of how we honor each other's words and work. Even though, at times, you may feel as if the distinction between your ideas and the ideas of others is unclear, you must make that distinction as clear as possible. This requirement to acknowledge the ideas of others applies whether the source is a faculty member, another student, a guest lecturer, or an off-campus friend or relative.

Authorship -- Instructors expect students to work together to discuss the results of laboratory work and other group assignments. However, all work handed in to the instructor (quizzes, exams, problem sets, lab data analysis, papers, peer reviews, etc.) should be the work of the individual student *unless the instructor gives written permission for submission of group work*.

Specific Advice -- Investigations "Advice to Authors"

Identify the author(s) on the first page, use double-spacing with 1 inch margins, and number each page. If your instructor asks for an electronic submission, name the file with your name and an indication of the subject of the paper (e.g., RWweasley_Chemotaxisassay.docx).

Scientific papers usually contain sections in order: Title, Abstract, Introduction, Methods, Results, Discussion, Acknowledgments, and References.

Title

The title tells *what* the paper is about, so the best time to determine it is after you have completed your 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 s/he wants to read.

Under the title, place your name and "professional address," which here is your specific course and laboratory section. This information should either be placed alone on a *title page*, or at the top of the first page in order to save paper (ask your instructor).

Below are examples of titles that (1) tell the reader very little about the investigation (**Bad**), (2) give specific information about the type of investigation, though they fail to inform the reader about the nature of the results (**Better**), and (3) indicate the objective and primary conclusions of the investigation in a concise manner (**Very Good**).

Bad: "Lab 2 - Plant phenotypes"

Better: "Growth and phenotypic variation in *Solidago gigantea*"

Very Good: "Heritability in *Solidago gigantea* is lower for growth than for leaf size"

Bad: "Lab 1: Heart Lab"

Better: "The function of frog hearts"

Very Good: "Epinephrine Increases the Strength but not the Rate of Contraction of Frog Hearts"

Bad: "Lab 1: Growth curves"

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Better: "Growing fibroblast cells in culture"

Very Good: "Lower serum concentration inhibits fibroblast cell growth *in vitro*"

Bad: Lab 3: Recrystallization"

Better: "Purification of organic compounds"

Very Good: "Purification of organic compound using hexane mixtures recrystallization"

Bad: "Laboratory exercise: Water analysis"

Better: "Drinking water quality in four samples"

Very Good: Source influences drinking water calcium content

Bad: "Laboratory Exercise: Greenhouse Gases"

Better: "Infrared Spectroscopy of Greenhouse Gases"

Very Good: "Molecular motion influences greenhouse gas properties"

Abstract

The abstract is a summary of each major part of the paper; it includes a brief introduction to the problem being studied, a brief statement of how the study was conducted, a brief summary of the major results, and a brief statement of the significance of those results. An abstract is usually between 100-200 words. Make every word count, so you can convey the most information in these few words. Clearly, it is best to write this section after you have written each of the four sections summarized in the Abstract.

The following is a good example of a Biology abstract.

Fluoxetine (Prozac) is a frequently prescribed antidepressant, identified as a selective serotonin reuptake inhibitor. Prozac's function as an SSRI leads to the popular belief that its antidepressant mechanism is related simply to an increased serotonin level in the synapse, due to the blockage of the serotonin reuptake pump. However, while some previous research has suggested that Prozac acts as an agonist, other research has suggested that Prozac also acts as an antagonist of 5HT_{2C} receptors, a function apparently contradictory to its role as an SSRI. We sought to further elucidate Prozac's effect on 5HT_{2C} receptors in the crayfish neuromuscular junction. To determine if Prozac acts as an antagonist of 5HT_{2C} receptors in crayfish *Procambrius clarkii* neuromuscular junctions, we compared excitatory postsynaptic potential (EPSP) amplitudes of control/5HT treatments, and control/Prozac and 5HT. Our results suggest that Fluoxetine does indeed act as an antagonist of 5HT_{2C} receptors in the crayfish neuromuscular junction.

Introduction

The introduction should briefly describe the background information for the reader to understand *why* the investigation was done. This should include the reasons for choosing the question being asked (why is it interesting?), some background on the system under investigation, and, if applicable, justification for hypotheses. A good introduction will mention the major issues that will be considered in the *Discussion* section, and that is why it may be helpful to write it, and particularly revise it, after finishing the other sections.

There are many ways to organize an introduction depending on its length and audience, but one principle is to begin by developing the general importance of your question, then move to the ideas leading to your specific study and question. Assume that the reader is at least moderately familiar with the general subject of the paper. In Biology, unless you are studying a model organism (e.g., *Drosophila*, *Arabidopsis*, *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. (If lengthy, this is sometimes placed in the Methods section). If you are using a particular experimental method, provide a rationale for having selected it. If your study tests a particular hypothesis, you might end your introduction by stating your hypothesis (with justification, of course) and describing in the most general terms how your investigation addressed it.

The following are two examples of good Biology introductions.

Biology Introduction Example 1

As urbanization pushes human settlements into natural ecosystems, the scientific community must develop novel paradigms to understand the ecological dynamics of these heterogeneous habitats and to quantify the impact of human activities on biological processes. Urban landscapes can be complex matrixes of disparate factors that both contribute to

disturbance, such as chemical pollution, and nurture biodiversity, such as well-designed parks. This complexity makes it difficult to tease out the ecologically relevant impact of urban disturbances (McDonnell & Pickett 1990) and evaluate the quality of ecosystem dynamics at local sites (Sadler et al 2006). To simplify these assessments, research in urban ecology employs the “gradient paradigm” which examines the variation in factors related to human disturbance with distance from a city center to less densely populated suburban and rural areas (Austin 1987).

Researchers then seek to relate this gradient of anthropogenic disturbance to easily measured indicators. These indicators can include populations or communities that are especially sensitive to various manifestations of human activity, such as soil compaction or the amount of paved area. Noss (1990) suggests that the organisms be wide spread, manageable to sample, and responsive to environmental changes (Figure 1).

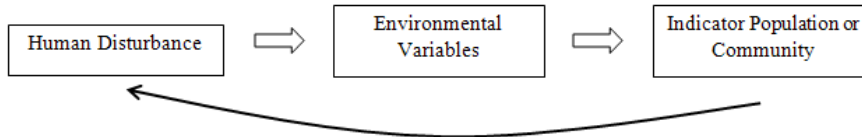


Figure 1. Biological indicators reflect the influence of human disturbance on environmental variables. In turn, the magnitude and spread of human disturbance can be extrapolated by assessing the indicator.

Previous research has identified bird and butterfly populations as reliable biological indicators that are remarkably sensitive to gradients of urbanization (Blair 1999). These models, however, respond to large-scale changes in the landscape, not small-scale changes that could impact micro-sites in vegetation or soil characteristics. Soil arthropods may fill this need by serving as ubiquitous, minimally motile, and easy-to-collect indicators of local site variables.

Additionally, the abundance and community structure of these arthropods has important ecological implications; soil organisms influence the rate of litter decomposition (Seastedt 1983) and balance of soil nutrients (Blair et al 1992). Some soil arthropod species graze on bacteria and fungus, impacting microbial communities (Dress & Boerner 2003).

Based on comparisons between sites with distinct natural histories, soil organisms do respond to dramatic disturbances, such as intense grazing (Mikola et al 2001; Clapperton et al 2002) and fire (Dress & Boerner 2004). Clapperton et al (2002) also concluded that Acarina, a group that dominates most samples across a wide range of environments (Dress & Boerner 2003; Cedpeda-Pizarro & Whitford 1989 and others), are especially sensitive to soil disturbance. Less research, however, has investigated the soil community’s responses to finer-scale variation like that associated with urban landscapes.

To determine if soil microarthropods can be used as an accurate biological indicator, this study examined their abundance and group diversity along a transect from the urban middle to the rural edge of a college campus in Grinnell, Iowa. We collected soil arthropod samples and assessed relevant site and landscape variables along the Prairie Walk, a kilometer long strip of prairie plantings.

The study investigated the following questions:

- 1) Does the Prairie Walk accurately represent an urban-rural gradient? Do site variables, such as soil compaction, organic matter, moisture, and temperature, and landscape variables, such as impervious surfaces, correlate with distance from the campus?
- 2) Do site and landscape variables—including soil compaction, soil moisture, soil temperature, soil organic matter, and proportion of landscape covered by impervious surfaces—reflect the abundance and diversity of soil microarthropods?
- 3) Does the abundance and diversity of biotic communities below ground, at the surface, and in the air correspond to an urban-rural gradient?

We anticipated that the sites furthest from campus would be subjected to less intense human disturbance and would exhibit greater percent soil organic matter and moisture and lower soil compaction, soil temperature, and surrounding impervious surfaces. Vegetation height may correlate with higher soil moisture and lower soil temperature because the leaves would shade the soil surface. Most likely, the most abundant and diverse soil microarthropod communities would inhabit these sites on the rural end of the gradient (Figure 2). We expected the arthropod communities both below and above ground to respond similarly to the urban-rural gradient.

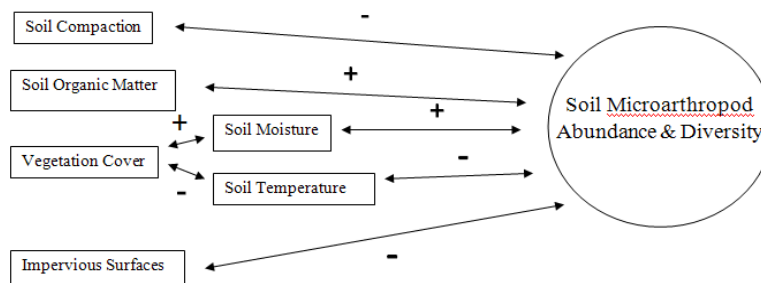


Figure 2. Schematic depicting predicted correlations between localized, environmental variables and soil arthropod abundance and diversity.

Biology Introduction Example 2

The knowledge of how nerves function is imperative to understand bodily functions in any animal. Many chemicals are involved in the nervous system and most of them have multiple effects. For example, 5-HT, one of the most abundant neurotransmitters in the nervous system, has been shown to increase excitatory postsynaptic potential (EPSP) amplitudes in the crayfish neuromuscular junction (Dropic et al. 2005 and Etkorn et al. 2006). The exact mechanism behind this is unknown, but the increase in EPSP amplitudes could be due to one of two intracellular calcium release receptors—that of either IP₃ or ryanodine (Mattson et al. 2000). Past research has also suggested a link between the effects of IP₃ inhibitors and 5-HT on EPSP amplitudes (Dropic et al. 2005). 2-APB is known to be an IP₃ inhibitor but may affect EPSP amplitudes through mechanisms other than an IP₃-induced Ca²⁺ release (Dropic et al. 2005). Through application of the IP₃ inhibitor 2-APB, we aim to determine whether 5-HT affects EPSP amplitudes through IP₃-induced Ca²⁺ release and if 2-APB and 5-HT have an unknown combined effect on EPSPs. This research is important because understanding the effects of 5-HT and the mechanisms through which it affects EPSPs will lead to a greater understanding of many neurological functions and how they occur.

We hypothesized that the application of an IP₃ inhibitor, 2-APB, will negate the effects of 5-HT on EPSP amplitudes. We already know that 5-HT causes an increase in EPSP amplitude (Etkorn et al. 2006), however, we wanted to know the combined effects of 5-HT and 2-APB. Our data supported our hypotheses that 5-HT works through an IP₃-induced Ca²⁺ release and that 2-APB decreases EPSP amplitudes when 5-HT has previously been applied to the preparation.

Methods

This section should carefully explain *how* the research was done. The level of detail should allow the reader to know exactly what you did and be able to repeat your study. Organize the sections logically, and not necessarily chronologically; the Methods section is not a diary of what you did every day. Use subheadings if there are more than a few paragraphs. Include all materials used, *but do not make lists*. Describe the exact conditions employed, how you gathered the data, and how you analyzed it precisely enough that someone else could repeat it. You may cite the lab manual or other sources for common techniques. If you develop your own technique, explain it in sufficient detail that another person could replicate your work. If you are doing a field study, indicate the location of the study and the dates on which it was carried out (since this may be important to the results). Do NOT do this for a laboratory study.

Fatal flaws: Do not present your Methods as a diary or the materials as a list. Write in complete sentences and organized paragraphs.

Below are some examples of good and bad Methods section practices:

Bad:

- "We measured growth rates and wrote *The Scientific Paper* | you measure growth rates? You don't need to tell the reader that you recorded the data or entered it into the computer.
- "The data were entered into Excel for manipulation." Likewise, graphical or spreadsheet programs do not need to be mentioned.
- "The cells were washed in saline and resuspended in medium" What solution did you use to wash the cells?
- "On the first lab day, we extracted the DNA and froze it. Then, the next week, we ran the DNA on an agarose gel." The methods section is not a diary of your lab work. Describe what you did concisely and in a logical order. It needn't be the exact order you did it in, unless that is critical.
- "Student t-tests are based on the principle..." Commonly used statistical tests generally need no explanation or citation. You should mention, however, what techniques were used to test which predictions.

Good:

- "We used a t-test to determine whether mean photosynthetic rates differed between the two light environments."

- “We prepared 5 solutions ranging in concentration from .0050M to .010M, by serially diluting a solution of .050M silver nitrate.”
- “We pelleted cells at 5000 x g for 5 minutes and then washed them in 0.05 M NaCl. Cells were pelleted again and resuspended at a concentration of 10⁸ cells per ml in peptone-glycerol broth.”

The following are two examples of good biology Methods sections.

Biology Methods Example 1

To establish populations of *Ceratopteris richardii* of different densities, we obtained 10 mg of pre-sterilized wild type spores from Carolina Biological Supply (Burlington, NC). We added 0.4 ml sterile water to suspend the spores and spread one drop of the suspension on a 60 mm petri dish containing a culture medium described in Klekowski (1969). This plate was labeled A. Five additional plates labeled B through F were each sown with one drop of a spore suspension that was two-fold more dilute than the previous one. These cultures were maintained in a culture dome under continuous light from four 34 Watt cool white, fluorescent bulbs (40 $\mu\text{mol}/\text{m}^2/\text{sec}$) and with the temperature at $28 \pm 2^\circ \text{C}$.

Determinations of the percent spore germination and gametophyte composition (as % males) were made at 7 and 14 days after inoculation (DAI) respectively. Determinations for plates A-C were made using a sampling method that counted between 5 and 10 cm^2 on each plate while plates D-F were counted in their entirety.

Biology Methods Example 2

For both the quantitative cell count and the turbidometric mass determination, the lab instructor supplied samples of the same 24-hour old stock culture of *Serratia marcescens*.

Quantitative Cell Count of *S. marcescens* An aliquot of the stock culture of *S. marcescens* (approximately 10^9 cells/mL) was diluted serially in sterile saline solution to generate three solutions with dilution factors (F_d) of 10^5 , 10^6 and 10^7 . Utilizing a flame sterilized glass spreader, 100 μL of each solution was spread onto sterilized peptone/glycerol agar plates, and the plates were then incubated for a 40 h period at 30°C , at which point visible colonies were counted. Plates yielding colony forming unit (CFU) counts between 25 and 250 were used to determine viable cell counts of the original undiluted culture (CFU mL^{-1}).

Turbidometric Mass Determination of *S. marcescens* An aliquot of the stock culture of *S. marcescens* (approximately 10^9 cells/mL) was diluted serially in sterile saline solution to generate four solutions with dilution factors (F_d) of 1.25, 2.5, 5, and 10. The absorption of these four solutions and an aliquot of the original culture were then measured at 550 nm using a Cary50 spectrophotometer utilizing a 1 cm pathlength plastic cuvette.

Results

Raw data you have collected should not appear in your paper. Rather, the *Results* section should summarize your findings and present your data for the reader to evaluate. One good way to approach the text of the Results section is to develop a set of questions about the data you gathered. Do not use questions that begin with “Why” -- these necessarily involve interpretation and 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.

Graphs and tables help the reader understand complicated data more easily than a written description. Note, however, that if the data can be easily summarized in the text, a figure or table is not necessary. The text should tell the reader the important points trends shown on the graphs or tables. Obviously the same data should not be presented in two different forms (e.g., a table should not contain data also summarized in a graph), so decide which format best informs your reader. Refer to graphs of any kind, as well as other pictorial materials, as “Figures” in the text. Call rows and columns of numbers and text “Tables” and number them separately from figures. Number tables and figures in the order in which you refer to them in the text. Call out each figure and table in the text. Ask your instructor whether tables and figures should be imbedded in the text, or placed in order at the end of the paper.

The following are two examples of good biology Results sections.

Biology Results Example 1

Our chemotaxis assay quantified the difference in motility between juvenile and adult *unc-60* mutants by measuring the ability to detect and move towards an *E. coli* food source. Both wild type juveniles and wild type adults were motile and exhibited a similar rate of chemotaxis (Fig.1 $t = -1.1, p > 0.05$). The *unc-60* juvenile worms possessed some motility, and the adults did not move at all. Our study shows that the *unc-60* mutation becomes more debilitating with age, as 19% of the juvenile mutants were able to move to the *E. coli* ring, while 100% of the adult mutants remained completely paralyzed (Fig.1 $t = -16.45, p < 0.05$). We also found that the *unc-60* juveniles exhibit less motility (19%) than the wild type juveniles (30%) (Fig.1 $t = -3.5, p < 0.05$).

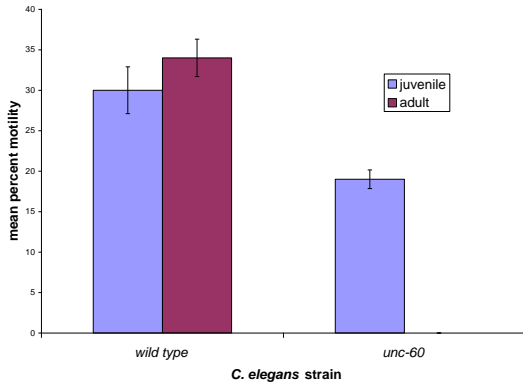


Figure 1. *Unc-60* mutants vs. wild type, adult vs. juvenile positive chemotaxis toward *E. coli* results. *Unc 60* juveniles are shown to be motile and can chemotax (19%), while adults were completely immotile ($t = -16.45, p < 0.05$). Wild type juveniles and adults are fully motile and maintain similar levels of motility (30% and 34% respectively, $t = -1.1, p > 0.05$). Motility was determined as presence in the *E. coli* perimeter. Error bars represent S.E $n=3$ in all cases.

Biology Results Example 2 -- Adapted from Pasachnik, S. and G.R. Ruthig. 2004. Versatility of Habitat Use in Three Sympatric Species of Plethodontid Salamanders. *Journal of Herpetology* 38: 434-437.

After accounting for the block effect, the species- treatment interaction was not significant (Table 1). However, both species and treatment effects were significant (Table 1). A posthoc Scheffe test determined that *E. cirrigera* had a significantly higher gain in mass than *P. cinereus* when all three habitat treatments were combined ($p < 0.05$) (Fig. 1). An additional Scheffe test determined that all individuals (regardless of species) within the stream treatment gained significantly less mass than individuals in either the bank or forest treatments ($p < 0.05$) (Fig. 1)

TABLE 1. ANOVA results for the change in mass/initial mass data. Change in mass is the difference in mass from the beginning of the experiment to the end of the experiment. Species include *Desmognathus fuscus*, *Eurycea cirrigera*, and *Plethodon cinereus*. Treatments include stream, stream bank, and forest.

	df	Mean	F	P
MODEL	17	0.027	2.87	0.001
BLOCK	9	0.024	2.16	0.016
SPECIES	2	0.063	6.72	0.002
TREATMENT	2	0.059	6.32	0.003
SPECIES × TREATMENT	4	0.008	0.86	0.492

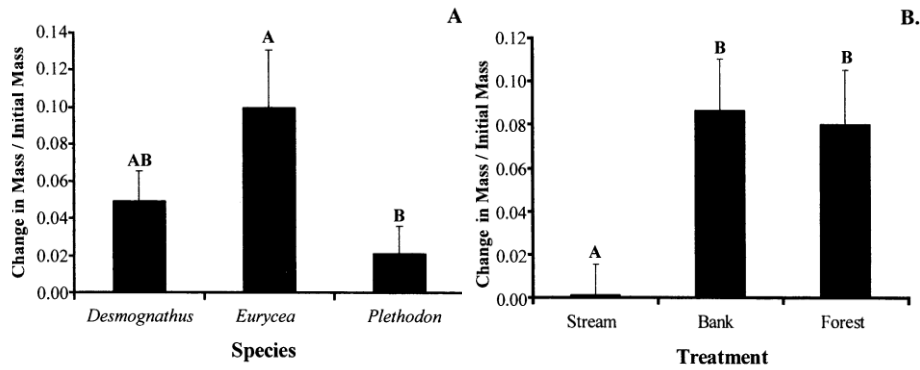


FIG. 1. (A) Species performance, independent of habitat treatment for *Desmognathus fuscus*, *Eurycea cirrigera*, and *Plethodon cinereus*. (B) Treatment performance, independent of species, in the stream, bank, and forest habitat simulations. Differing letters depict significant differences. Error bars represent standard error of the mean. N ranges from 6-10.

Discussion

The role of the *Discussion* section is to interpret the meaning of your results. Proceed in this section from the specifics of your study to the general question that motivated the study (just the opposite from the Introduction!). Consider addressing the following points in order:

1. Remind the reader of important trends in your data and how those results relate to your hypothesis or goals.
2. Provide an explanation for the most interesting or relevant results. This might include references to other studies that showed similar or different results. Include references that help support your explanations.
3. Discuss the relevance of your results and their interpretation to the larger questions that motivated the study.
4. End the discussion with a summary, the “take home lesson” that you want your reader to remember about your work. Indicate interesting future directions for study, rather than simply summarize (again) your results. In other words, build on the interpretations you have just provided, so that those arguments in the previous paragraphs matter. Some papers have this summary as a *Conclusion* section.

The length of the Discussion section depends on the scope of your study. A good way to approach the writing of this section is to consider each of the above points as the subject of a short paragraph. You can later expand or combine these after laying out your ideas.

Here are some tips on common errors in Discussion sections:

- Do not infer that because your hypothesis wasn't supported, you made a mistake. “Negative” results can be important too, since they may suggest that your hypothesis was incorrect. What would be the benefit of testing hypotheses, if you could never reject them? If you did make an error somewhere in your investigation, acknowledge it and move on.
- Do not omit or minimize discussion of findings that you did not expect. Such results are often the most interesting.
- Do not center your discussion around a proposal to repeat your experiment with a larger sample size! This is often true and not as interesting as suggestions for new investigations that arise from your findings.
- Do not end the paper with the phrase, “. . . but of course more work needs to be done.” Describe what *kind* of work would be the most interesting extensions of the study and why.

Acknowledgments

In this section, thank any persons who contributed any significant help during the study. Such contributions include help in experimental design, collection of data, preparation of graphs, drawings or the manuscript, critiquing a draft of the manuscript, and financial or physical support of the work. Always acknowledge your partners in group projects!

References

Standards for citation vary somewhat among journals. The *Investigations* formats are similar to those in many (but not all) journals in biology or chemistry. **It is critical that you do not use MLA format or footnotes to cite your references.** Since the forms differ between biology and chemistry journals (and even within the disciplines), it is also critical to ask your instructor which of the standards below apply to your class. When scientists submit a paper for publication, they read and adhere to the guidelines set for each particular journal. **In the same manner, you should think of each paper you submit as needing to adhere to the guidelines set by each particular professor.**

List only the papers or other publications that were *directly cited* in your paper. A References section is not a bibliography. Citing a paper means you read it -- reading the abstract is NOT sufficient, unless specifically allowed by your instructor.

Investigations Biology References Convention

Cite references in one of two ways in the text of your paper:

1. Mention the authors' names as part of your sentence followed by the year of publication in parentheses. When there are three or more authors, give the first author's last name, followed by "et al." (Latin for "and others"):

Sullivan et al. (1998) described the use of delta-crystallin as a marker of lens induction during differentiation.

2. Place authors' names and the year of publication in parentheses following ideas or results from the article:

Experimental studies of several species indicate that tradeoffs between growth and male function may not be predicted by resource allocation models alone, unless meristem availability is also considered as a resource (Eckhart and Seger 1999).

List references alphabetically according to the first author. Standards for the reference sections vary widely among journals, primarily in details of punctuation. Please use the appropriate form for each type of reference below:

Journal article:

Author(s). Year. Title. *Journal* Volume:pages.

Sullivan, C.H., P.C. Marker, J.M. Thorn, and J.D. Brown. 1998. Reliability of delta-crystallin as a marker for studies of chick lens induction. *Differentiation* 64: 1-9.

If you cite more than one paper by the same author(s) the papers should be listed chronologically (earliest first). If a paper has more than five authors, use "et al" list the first five.

Book chapter of edited volumes

Author(s). Year. Title of chapter. *In* Editors names (eds.). Title of book. Publisher, Place of Publication, pages.

Eckhart, V.M., Seger, J. 1999. Phenological and developmental costs of male sex function in hermaphroditic plants. *In* Vuorisalo, T.O. and Mutikainen, P.K. (eds.). Life history evolution in plants. Kluwer, Dordrecht, pp. 195-213.

Book

Author(s). Year. Title. Publisher, Place of Publication.

Voyles, B.A. 1993. The biology of viruses. Moseby, St. Louis.

Web pages (use sparingly!)

Author. publication date. Page title. Site title. URL. date you accessed it.

Harr, J. 2002. Plants of Cedar Creek – Asteraceae. Cedar Creek LTER.
<http://cedarcreek.umn.edu/plants/narratives/asteraceae.html> . 7 January 2004.

Investigations Chemistry References Convention

Citations appear either as footnotes or endnotes. They are numbered in the text in the order referred. Numbers are either in superscript or enclosed in brackets, as in the following example:

“(Name) and co-workers [1,2] have previously studied the effect of molecular weight on vapor pressure for chlorinated compounds.”

You may also cite a source at the end of a paraphrased sentence:

“Mass Spectrometry has previously been shown to be a rapid, sensitive technique for determination of molecular weights of organic compounds. [3]”

The standard format for full citations is:

1. Lastname, I. N.; Author2, I.N. “Title”, *Journal Name* ,
Year, Volume, PageNumber.

Examples are below:

Levandoski, M.M., Lin, Y., Moise, L., McLaughlin, J., Cooper, E., and Hawrot, E. “Chimeric analysis of a nicotinic acetylcholine receptor reveals amino acids conferring sensitivity to a-bungarotoxin”, *J. Biol. Chem.*, **1999**, 274, 26113.

Marzluff, E.M.; Campbell, S.; Rodgers, M.T.; Beauchamp, J.L. "Collisional Activation of Large Molecules is an Efficient Process", *J. Am. Chem. Soc.*, **1994**, 116 , 6947-6948.

Are you interested in streamlining the processes of doing your references section? Read the following!

RefWorks is a bibliographic software package available at no cost to Grinnell College students through the Web that enables you to:

- build a bibliography in a wide variety of citation styles (including styles recommended in "Investigations")
- import references from many data sources
- organize your research
- include citations while you write your paper

Since RefWorks is available through the Web, there is no software to download and update and you can access your personal account from any computer connected to the Internet.

RefWorks can be accessed at: <https://www.refworks.com/Refworks/>

If you are logging in for the first time, you will be asked to register. You will receive an e-mail confirming your registration. You can also access RefWorks from off-campus using a Group Code available from any Librarian. Questions? Contact Kevin Engel ([engelk]; Science 2105; x4234) or another Librarian (x3353; [query]).

Evaluation of Scientific Papers

Evaluation and revision is the key to better writing. This means you must start writing early, finish a complete draft well before the due date, seek out reviewers, and revise. Scientists never send manuscripts to journals without having several people not associated with the study read and evaluate it. A good reviewer reads critically, i.e., s/he lets the author know both the strengths and weaknesses of the writing. People who just like to tear things (and people) apart, or who are afraid or unwilling to point out problems, are equally useless as reviewers. So who should review your manuscript? The candidates:

The Scientific Poster

The author -- Take some time away from your paper and then come back to it as a reviewer. Read it aloud. How does it sound? Does one sentence flow to the next? Is there needless repetition? Do your explanations make sense? This may sound foolish, but it is a tested method. It may also help you learn to recognize your own bad writing habits.

Other students -- Since other students are your intended audience, why not test out the paper on one of them? You may want to pick someone NOT in your class, particularly if all members of the class are writing a paper on a similar topic. Your reviewer should be thanked in your *Acknowledgments* section.

The Writing Lab -- The folks in the Writing Lab are a wonderful resource. Going to the Writing Lab is not a punishment, but an opportunity. Many of your professors have used the writing lab for their own work, including this very document. Make an appointment and start writing well in advance.

The professor -- Your instructor may be willing work with you on your paper. Make an appointment well ahead of time (professors have busy schedules) and come in well prepared to discuss *specific* aspects of the paper. Don't expect your instructor to read a full draft at a moment's notice to screen for problems.

***Do you get the sense that all this can't be done the night before the due date?
You got it.***

Methods of evaluations of papers will vary among your professors. In **Appendix C on page 73** we show two examples of evaluation rubrics that have been used in Biology classes for evaluating scientific papers. Ask your instructor how s/he will evaluate your paper.

The Scientific Poster

What is a poster and why do you do it?

Professional scientists regularly present the results of their work at local, national, and international meetings. At most scientific meetings, posters are the primary means by which scientists exchange information about their work. The poster, although a smaller unit than the published journal article, is thus a fully professional entity, and almost always the first form in which your story is made public. It is also the most egalitarian form of presentation in that tenured researchers and students alike use it. Its principal advantage is that it promotes extensive two-way communication between the presenter and the audience. Not only are results and conclusions presented to the audience, but also the presenting scientist usually receives ideas and suggestions that help in planning future experiments.

What is a poster? A poster is a visual way of presenting scientific results. A good poster is virtually self-explanatory; it will contain the elements of a paper (Title, Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusions, and References), but it is a distinct form in which different elements are emphasized. There are several examples of research posters distributed around the science building. Look them over. If you still have questions or are unclear about the elements and structure of posters, talk to your instructor.

The poster audience may be divided into three main groups. At professional meetings, Group 1 comprises those colleagues, collaborators, and students who follow work in your area of biology very closely. In Bio 150, that means the other students who have chosen to focus on topics very similar to yours. This group is familiar enough with the methods and background of your work not to find detail intimidating. At professional meetings, Group 2 includes those scientists who work in the same general area as you, but not on your particular specialty. This group is much larger than Group 1; in this course, it includes the other members of your course. At professional meetings, Group 3 would include those researchers whose work is largely unrelated to yours. In this course, it includes other students within the Science Division who may come to view your poster, as well as the very general audience likely to be present at Parents' Weekend. Keep in mind that your poster must address the needs and abilities of all three groups in order to be successful!