Lab Report Guide: How to Write in the Format of a Scientific Paper

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How to use this guide

The purpose of this guide is to help you write lab reports in biology. It is designed to make the writing process clear, and should help protect you from unnecessary frustration.

Before writing your first report, read "The Fundamentals" below. Then read the brief "Overview" for each section of the lab report; the Overviews are found in boxes throughout this document.

When you are ready to start writing a section of your report, re-read the Overview for that section. Following each Overview is an FAQ (Frequently Asked Questions) for that section. You may find it helpful to scan the FAQ for each section before you begin writing, or you may choose to refer back to the FAQs as you come up with a question. Alternatively, you may find the FAQs most useful as you revise a particular section. If you have additional questions not covered in the FAQ, please ask your lab instructor or TA. Use the model examples from published scientific research papers as needed. Read the "Revising and Finishing" section as you are preparing to turn in any portion of your paper, and again before you hand in the final draft of your paper.

The Fundamentals

In order to write a lab report in the format of a formal scientific paper, it is important to see where the format fits within the broader context of scientific communication. As a student and a member of the general public, you understand one level of scientific communication already. When scientific information is communicated to you, it is done through newspaper articles, textbooks, books in the "popular science" genre, and magazines such as Scientific American. This is a crucial part of communication in science, though many scientists may not participate in it directly; science writing is an established field of its own. Well-written articles or books of this sort are careful to present all the necessary supporting information so that people can easily follow the arguments and evidence surrounding the scientific research being presented.

Scientists also communicate with other scientists, inside and outside their immediate field. These communications generally fall into one of two types: primary research articles and review articles. In a primary research article, a scientist (or more commonly, a group of scientists) report what they set out to investigate, what studies or series of experiments they performed, what results they found, and what they think the results mean. In a review article, a knowledgeable scientist will summarize the results of many primary research articles (by many different authors) and try to put together a cohesive story of the current state of research in their field. Depending on the journal where scientists publish their paper, they may be writing for the very specific audience of other scientists in their field (as in the *Journal of Immunology*) or they may be writing for a broad group of scientists from a variety of fields (as in the prestigious journal *Science*). Many journals publish both primary research articles (as a body of writing, these are referred to as the "primary literature") and review articles (sometimes called "secondary sources"). Some journals publish only review articles (such as the journal *Trends in Ecology & Evolution*).

The purpose of this guide is to help you learn to write a primary research article in biology. As with most writing, your goal is to tell a clear story to your audience. As in other courses, you will do this by presenting an idea (or thesis), supporting it with evidence, and explaining the implications of your idea. While the format of a primary research article is rather formulaic compared to the writing you will do in other classes, the writing techniques you use are the same. The basic components of a scientific paper are (1) an **Abstract**, or summary of the entire paper, (2) an **Introduction** to a question you studied, (3) the **Materials and Methods** you used to address the question, (4) the **Results** of your studies, and (5) a **Discussion** of the meaning of those results. This structure reflects the "Scientific Method" you may have learned about in high school, in which scientists make a hypothesis, test the hypothesis, gather results, and make conclusions based on their results. While this simplified structure is a useful tool for reading and presenting scientific research, it rarely reflects the process of doing science. A research scientist may spend a lot of time trying experimental

techniques which do not answer their question they way they had hoped, or they may get results which cause them to redefine their initial questions. The reality is much messier than the end presentation.

Scientists actually use the prescribed format of a scientific paper to help them organize their ideas around a study. Writing and presenting information in a coherent way can help them (and you!) gain a clearer understanding of their experiment and its implications. The process of writing is actually a wonderful tool you can use to deepen your understanding. This is a bit circular: understanding ideas will make your writing easier; if you do not understand what you're writing about, you will not be able to present your ideas clearly. However, by *trying* to write about ideas, and then revising your writing, you will identify gaps in your understanding and have incentive to fill them in. Plan to use the process of writing in the formal structure of the scientific paper as a tool for understanding.

The Parts of a Scientific Paper

Title

Overview

The title is a specific, informative summary of the results of your study. As in all writing, the title is the first clue to a potential reader that they should be interested in reading your paper; in science, that means being very direct about what information is present in the paper. Check with your instructor on whether you need to make a separate title page or not. You should include your name on your paper, and list your lab partners if you worked together to collect the data.

Example Titles

Here are a few titles of research papers published by Carleton faculty and Carleton alums. Note the level of detail present in the titles, and the clear statement of results in some. You can look through the Literature Cited section of this guide to see additional titles of scientific papers.

A role for recombination junctions in the segregation of mitochondrial DNA in yeast (Lockshorn et al. 1995)

An edge effect caused by adult corn-rootworm beetles on sunflowers in tallgrass prairie remnants (McKone et al. 2001)

Changes in biomass, aboveground net primary production, and peat accumulation following permafrost thaw in the boreal peatlands of Manitoba, Canada (Camill et al. 2001)

Mechanoelectrical transduction assisted by Brownian motion: a role for noise in the auditory system (Jaramillo and Wiesenfeld 1998)

Random amplified polymorphic DNA markers reveal genetic variation in the symbiotic fungus of leaf-cutting ants (Doherty et al. 2003)

The Abstract

Overview

This section of the scientific paper is commonly written last, after the rest of the paper. It concisely summarizes the reason for the experiment (from the Introduction section), the general methodology used in the experiment (Materials and Methods section), the main findings of the experiment (Results section) and the implications of those findings (Discussion section). The order of these components is more flexible in the Abstract than in the overall paper; in some cases it might be logical to describe and discuss a result in the same sentence, and move onto another result in a new sentence.

FAQ

1. What verb tense should I use in my Abstract?
2. Should my Abstract contain multiple paragraphs?
3. Should I use bullet points or numbers to list the ideas in my Abstract?
4. How long should my Abstract be?
5. Should I refer to my figures in my Abstract?
6. Should I cite other papers in my Abstract?

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1. What verb tense should I use in my Abstract?

   You will use past tense in writing most of your Abstract, because you are describing an experiment which has already been done. For some statements which summarize your Discussion section, present tense might be more appropriate, since you might be proposing ideas in the present tense.

2. Should my Abstract contain multiple paragraphs?

   Generally, a single paragraph is fine for an Abstract, since all the information you are

presenting supports a single goal: to give an overview of the rest of the paper. There may be rare occasions when your story can logically be broken into paragraphs; if this helps convey your ideas, go ahead and use multiple paragraphs.

3. Should I use bullet points or numbers to list the ideas in my Abstract?

   No; write out your Abstract in prose, unless the specific journal format you are using discourages this.

4. How long should my Abstract be?

   In scientific writing, and in Abstracts in particular, a direct, concise writing style is highly valued. The Abstract is usually less than 250 words. You need to have enough information in your Abstract that people will know after reading it whether or not it is relevant for them to read your whole paper. Just because the Abstract is brief does not mean that it is vague; often you can strengthen your abstract by stating a key result or statistic very precisely. The Materials and Methods component of abstracts is usually the most abbreviated section; it is often sufficient to state the general methodology used without explaining the specific protocol.

5. Should I refer to my figures in my abstract?

   No.

6. Should I cite other papers in my abstract?

   No.

Example Abstracts

Here are three abstracts from research papers published by Carleton faculty and Carleton alums. In each abstract, look for the components of a good abstract listed in the Overview above.

From Garrettson et al. 1998:
Nests of leaf-cutting ants (Hymenoptera: Formicidae: Attini) are abundant disturbances in Neotropical rain forests, and could affect the plant community both while the nests are active and after they are abandoned. We measured the diversity and abundance of understorey plants (<1 m in height) in the area around active and abandoned nests of leaf-cutting ants (*Atta cephalotes*) at the La Selva Biological Station in Costa Rica. Sample quadrats on active nests had reduced diversity (number of morphospecies) and abundance of both small (height < 10 cm) and large (10 cm-1 m) understorey plants, when compared to the nearby forest floor (3 and 13 m from the nest edge). Abandoned nests had greater diversity and marginally greater abundance of small understorey plants relative to nearby forest; there was no difference in diversity or abundance of large understorey plants. Leaf-cutting ant nests create gaps in the plant understorey when active, but serve as centres of recruitment for small plants after they are abandoned. Thus, like canopy gaps, ant nests could play an important role in recruitment of new individuals and maintenance of plant species diversity in tropical forests.

From Jones et al. 1991:
Presence or absence of nesting behavior during spontaneous or hormone-induced oviposition was determined in captive, oviparous lizards (*Anolis carolinensis* and *Sceloporus undulatus*). The occurrence of nesting behavior (digging of a nest cavity, covering the egg(s) with substrate) was determined directly by observation of ovipositing females as well as indirectly by whether eggs were covered (buried). Under uncrowded conditions in large terraria, most females of both species nested. However, under crowded conditions (*S. undulatus*), or in small cages (*A. carolinensis*), females oviposited without displaying species-typical nesting behavior. Facultative suppression of nesting behavior during oviposition can occur in nature as well, and this inhibition of behavior may be adaptive. We hypothesize that the absence of nesting behavior in viviparous lizards may be controlled by physiological mechanisms similar to those that control facultative suppression in closely related oviparous species

From McKone et al. 2001:
The once-extensive tallgrass prairie community of North America has been reduced to small remnants, many of which are surrounded by intensive corn (*Zea mays*) agriculture. We investigated adult corn-rootworm beetles (Chrysomelidae: *Diabrotica* spp.), important pests of corn, on sunflowers (Asteraceae: *Helianthus* spp.) in prairie remnants in southeast Minnesota. Large numbers of beetles invaded the prairie from surrounding corn fields in late summer. *D. barberi* and *D. virgifera* were captured on sticky traps in all locations in the prairie, but abundance was much greater near the edge adjacent to corn. We observed *D. barberi* (but not *D. virgifera*) feeding extensively on sunflower pollen and occasionally on other flower parts, such as petals. Sunflowers located

nearer corn fields sustained more floral damage than those farther from corn. To determine the effect of beetle damage on seed set, we enclosed sunflower heads in bags with either zero, two, or four D. barberi adults. Seed set was reduced in heads enclosed with *D. barberi*. Thus, this agricultural pest may interfere with the successful reproduction of sunflowers and possibly other prairie composites that flower in late summer. Given the small size of most prairie remnants and the abundance of this flower-feeding beetle in landscapes dominated by corn agriculture, *D. barberi* may affect the sustainability of prairie plant populations.

The Introduction

Overview

The Introduction section answers your reader's question: "What question (problem) was studied?" (Day 1994). In this section, you give your reader the background to understand your question and then present your question. In asking a scientific question, you are often trying to fill a gap in a field; in the introduction, you are explaining what surrounds that gap and why it should be filled with your experiment. As you describe what is known already, you will need to cite the work of other scientists; often an Introduction section contains many citations. The structure of the Introduction is often an inverted pyramid, starting with a broad description of the background and narrowing down to the particular question being asked. (This is often the inverse of the Discussion, which might start with a focus on the particular results of your experiment, broaden to apply your results more generally, and then incorporate other questions or ideas for future study.) Many people write their Introduction after they have written their Results section but before writing their Discussion section; others find it useful to construct their Introduction and Discussion at the same time.

In some journals, scientists summarize their results in the final sentence of their Introduction; check with your instructor to see if this is appropriate for your assignment.

FAQ

1. What verb tense should I use in my Introduction?
2. Should I use multiple paragraphs in my Introduction?
3. Should I use first person in my Introduction?
4. How much background information do I need to provide?
5. It seems like my Intro sounds a lot like the introductory information in the lab manual. Should I be concerned about this?
6. How do I cite information from the lab manual that is from another source originally?

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1. What verb tense should I use in my Introduction?

   You will most often use past tense in your Introduction, because you are describing work which has already been done by other scientists. When you write about your question or goals, it may make more sense to use present tense.

2. Should I use multiple paragraphs in my Introduction?

   Yes. As you narrow your focus to your question, you will want different paragraphs to apply to different levels of description.

3. Should I use first person in my Introduction?

   Check with your lab instructor about the use of first person; if this is acceptable to them, it may be appropriate in your Introduction when you introduce your question. It will probably not be appropriate when you are writing about the work of other researchers.

4. How much background information do I need to provide?

   This will depend on what you think is important for the reader to know for the rest of the paper. Some background on the organisms you are using, for example, is generally important to understanding the experiments. If other researchers have studied similar questions, it is important to set your work in the context of their results.

5. It seems like my Intro sounds a lot like the introductory information in the lab manual. Should I be concerned about this?

   Yes; rather than trying to paraphrase all the information from the lab manual, you should consider which points seem relevant to the story you are telling. If you think your prose seems too similar, try taking briefer notes from the manual and then re-writing the section based on your

notes. Good paraphrasing of information is done such that the meaning of an idea is kept intact, but none of the sentence structure or order is traceable. You should still cite the lab manual even after good paraphrasing.

6. How do I cite information from the lab manual that is from another source originally?

   Normally, if you were writing a real scientific paper, you would read the original work and cite it directly. Never directly cite a paper you have not read yourself. Very rarely, you will see a reference written as follows: (Uhler 1951, as cited in Carleton Biology Department 2006). Because this is used so infrequently, for the purposes of the introductory biology lab reports, if you feel you need to cite some information of this nature you may cite the lab manual directly. In future classes, always check with your instructor to find out what they would like you to do.

7. Should I quote other sources directly?

   No; in scientific papers, direct quotes are extremely rare. They are only used if there is something important about the *way* a thing is stated. Normally, scientific results, ideas, and conclusions are paraphrased. If you have questions about this, please talk to your instructor. We also encourage you to refer to the Academic Honesty pamphlet given to all entering students.

Example Introduction

Here is the Introduction of a research paper published by Carleton faculty and Carleton alums.

From Hinman et al. 1997:
Many of the venomous New World coral snakes (*Micrurus* and *Micruroides*) have a distinctive pattern of red, black, and yellow rings (Campbell and Lamar 1989; Savage and Slowinski 1992), which typically appear in the sequence red-yellow-black-yellow (the "tricolor monad" of Savage and Slowinski 1992) repeated multiple times on each snake. Relatively harmless coexisting snakes in several different genera have a similar appearance, and most recent investigations have concluded that these are cases of Batesian mimicry (Greene and McDiarmid 1981; Pough 1988a; Campbell and Lamar 1989; Savage and Slowinski 1992). Though it is clear that a precise mimic of a dangerous or unpalatable model often gains protection from predation (see Waldbauer 1988 for a review), the gradual evolution of mimicry requires that partial mimics gain some fitness benefit from even a poor resemblance to model species (Fisher 1958; Sheppard 1959). There is evidence that partial mimics gain limited protection from predation in some insect systems (e.g., Morrell and Turner 1920; Pilecki and O'Donald 1971; Shideler 1973). A large number of neotropical snakes have some elements of the coral snake pattern (Pough 1988b), but there is very little information on the protective effects of partial mimics largely due to the extreme difficulty of observing predation events in the field.

Brodie (1993, following Madsen 1987) pioneered the use of plasticine replicas of coral snakes to gather data on rates of predation by free-ranging birds in the natural habitat of coral snakes. The soft plasticine retains the imprint of any attempted predation, which can be used to identify the predator as bird, mammal, etc. (Brodie 1993). Using this method, Brodie (1993) showed for the first time that the coral snake pattern reduces the rate of avian predation for replicas of both true coral snakes and coral snake mimics.

Here we extend Brodie's (1993) method to determine bird attack rates on partial coral snake mimics that have color and pattern combinations not found in any living snake. The coloration of coral snakes includes a number of elements that can vary independently: ring color, ring width, and order of the arrangement of rings. There is no historical information about the phenotypes of partial mimics in the initial stages of the evolution of coral snake mimicry, but we assume that incipient mimics would have only some of the elements of the true coral snake pattern. Partial coral snake replicas were constructed to address three questions about predation by free-ranging birds in the natural habitat of coral snakes. Compared to coral snake mimics and plain brown controls, we tested the effect on predation rate of the following: (1) replicas with rings that mimic the coral snake width and arrangement, but made up of the "wrong" colors; (2) replicas with a repeated pattern based on just *one* yellow ring (red-black-yellow) as opposed to the common pattern of *two* yellow rings (red-yellow-black-yellow); and (3) replicas with rings that differ in width from those of the coral snake model.

The Materials and Methods Section

Overview

The Materials and Methods section answers your reader's question "How was the problem studied?" (Day 1994). In this section, you describe the procedures you followed and the techniques you used to perform your experiments. You will include enough detail so that someone familiar with basic biological techniques could reproduce your experiment. If you collected organisms for your experiment, you will include the dates and locations of collection. You also will name any statistical tests you performed to analyze your results. Many scientists choose to start writing a scientific paper by writing this section; you can begin writing as soon as you have performed the experiments, while the procedures will be fresh in your mind.

FAQ

1. What verb tense should I use in my Materials and Methods?
2. Should I use multiple paragraphs in my Materials and Methods?
3. Can I use first person in my Materials and Methods?
4. Can I use subheadings in my Materials and Methods?
5. How do I know how much detail to put into my Materials and Methods section?
6. I am reporting on a set of class data compiled from many lab groups; do I need to refer to this in my Materials and Methods?
7. I am reporting on class data, and some students used a different technique or protocol than I did. Do I need to include their technique in my Materials and Methods section?
8. Do I need to include my statistical calculations in my Materials and Methods section?

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1. What verb tense should I use in my Materials and Methods?

   You should use the past tense, since you will be describing things you have already done.

2. Should I use multiple paragraphs in my Materials and Methods?

   Yes. Use the presence of multiple paragraphs to help the reader organize the information you are presenting.

3. Can I use first person in my Materials and Methods?

   Yes, but double-check with your instructor first. Traditionally, Materials and Methods sections have been written in third-person, passive voice ("this was done") rather than first person, active voice ("I did this"). This is changing, and there are now strong proponents of the use of first person in scientific writing. If your instructor suggests using first person, you may still decide that passive voice is appropriate in some descriptions; use what you know about good writing (e.g. placing the important focal point of your sentence near the beginning) in your decisions. *American Naturalist* (the journal whose formatting we are using for our citations) allows the use of first person.

4. Can I use subheadings in my Materials and Methods?

   The use of sub-headings is acceptable if it clarifies your ideas for the reader. If your Materials and Methods is extremely short, sub-headings probably are not necessary (a sub-section with only one or two sentences seems inappropriate).

5. How do I know how much detail to put into my Materials and Methods section?

   This is probably the trickiest part of writing this section. You want to put in key information so that someone could repeat the experiment, but you should not write a diary of what you did. You may assume that things like "electrophoresis" and "spectrophotometry" are standard techniques. While there are details you would need to share (for example, voltage of the power supply or wavelength of the spec), you do not need to describe how to load or run a gel, or how to take a reading with the spec. You can assume the reader knows how to treat reagents (like when to keep something on ice). Do not assume the reader has the exact same equipment as you; unless you are presenting a truly novel technique, details peculiar to your lab equipment are not necessary.

   Somewhat confusingly, often the details which are important for a Materials and Methods section

were not that important to you as you ran the lab. The fact that you used a particular type of gel in lab was irrelevant to you, since you didn't have much of a choice. However, this detail is crucial for your Materials and Methods section. People reading your report will want to know the volumes and/or concentrations of solutions you used, but they won't care that they were kept in a blue plastic bottle. Similarly, nobody needs to know how you labeled your materials (unless that will be relevant later in the report) or how the logistics of lab groups worked.

6. I am reporting on a set of class data compiled from many lab groups; do I need to refer to this in my Materials and Methods?

   You do not need to specifically refer to who collected which data, but you do need to account for the data you are reporting in your results. Your Materials and Methods should be consistent with your results: if you are reporting on data from ten fish (and your lab group took measurements on only one fish), you need to explain that data were collected from ten fish. It is unnecessary to specify that you only collected data from one fish, unless you plan to discuss some peculiarity in the data and need to explain differences in different lab groups' procedures.

7. I am reporting on class data, and some students used a different technique or protocol than I did. Do I need to include their technique in my Materials and Methods section?

   Yes, but double-check with your lab instructor. If you are presenting results which relied on techniques, even if you did not personally use those techniques, you still need to clarify to the reader how those results were obtained.

8. Do I need to include my statistical calculations in my Materials and Methods section?

   No. You should merely state the statistical test which was used, specifying exactly what was being compared with the test. You do not need to include your calculations anywhere in your report.

Example Materials and Methods Sections

Here are some excerpts from scientific papers published by Carleton faculty and alums.

from Linksvayer et al. 2002:
We measured rates of foraging and hitchhiking at two locations for each nest: one where the selected foraging column entered the nest and another at 10 m along the column toward the foraging site. Foraging rate was recorded as the number of ants carrying a leaf fragment that passed a set point on the trail during a one-minute observation period. For each location, the foraging rate was recorded during five one-minute periods spaced one minute apart. Hitchhiking rate was measured at the same times as foraging rate, and was recorded as the number of laden foragers that carried leaf fragments with one or more hitchhikers.

from Massardo et al. 2000:
All observations were made with a model BHS-RFK epifluorescence microscope equipped with appropriate objectives (Dplan Apo 100UVPL and 100UV; Olympus Optical Co., Ltd., Tokyo, Japan). Staining of fixed cells by 4',6-diamidino-2-phenilindole (DAPI) was carried out as follows. Cells were fixed with 4% gluteraldehyde for 30 min at room temperature by directly adding gluteraldehyde into the culture. After two changes with NS buffer (20 mM Tris-HCl pH 7.6, 0.25 M sucrose, 1 mM EDTA, 1 mM $MgCl_2$, 0.1 mM $ZnSO_4$, 0.1 mM $CaCl_2$, 0.8 mM PMSF, 0.05% 2-mercaptoethanol), cells were stained with 1 μg/mL of DAPI dissolved in NS buffer on a glass slide (Williamson and Fennell 1979; Miyakawa et al. 1994). Samples were examined under excitation by UV light and photographs taken with a Neopan 1600 film (ASA 1600; Fuji, Tokyo, Japan) with an exposure time of 12.8 s.

from McKone et al. 2000:
Statistics
We used nonparametric tests (Mann-Whitney test, Kruskal-Wallis test) for our analysis because insect counts often deviated from normality or had unequal variances among treatments. After the Kruskal-Wallis test, we performed multiple pairwise comparisons between treatments with Dunn's nonparametric test for unequal sample sizes (Zar 1996).

from Sawai et al. 2003:
Mononuclear cells were isolated from spleens using aseptic technique by grinding through a mesh sieve followed by density centrifugation on Lympholyte (Accurate Chemical & Scientific Corp., Westbury, NY). Cells were counted by either trypan blue

exclusion using a hemacytometer or, in some cases, using ViaCount stain (Guava Technologies, Hayward, CA) containing the intact cell-impermeant nucleic acid dye 7-AAD (Schmid et al. 1992). The viability of the mononuclear cells was typically > 95%.

The Results Section I: Analyzing Data

Overview

Before you can begin writing your Results section, you will need to analyze the results of your study or experiment. Most scientists perform this step before they write any sections of their paper—they are excited to find out the results of their research! This analysis may include calculations of average values for different experimental conditions or treatments and calculations of statistics to help determine if the different treatments had an effect or not.

Raw data are typically not presented in a scientific paper; if statistical analyses are used, these are briefly described in the Materials and Methods section. The results of the analyses are presented in Tables, Figures, and the text of the Results section).

FAQ:

1. What is a sample size? What is "n"?
2. What is an average?
3. What is a standard deviation?
4. What is a standard error?
5. What are the common types of statistical analyses used in Intro Bio?
6. When do I use a Student's t-test?
7. When do I use a χ^2 test?
8. How are results of statistical analyses presented?
9. How do I know whether my results are significantly different or not? What is a p-value? How do I know what a p-value means?
10. How do I determine a p-value?
11. What are "degrees of freedom?"

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1. What is a sample size? What is "n"?

The number of observations made is called the "sample size" and referred to as "n," or sometimes "N." The sample size is important to report so that other scientists have a clear idea of how many observations your data are based on. You can imagine you might be more convinced by data from someone who looked at 400 ladybugs rather than just 5. Larger sample sizes can help you be more persuasive and also allow statistical tests to be stronger.

2. What is an average?

An average is a common way to summarize multiple results of an observation or test. An average, also called a mean, is calculated by adding together the values you got for the same type of observation and dividing by the number of observations you made. For example, if you wanted to find out how many spots ladybugs have, you might catch several ladybugs and count the spots on each. If you caught five ladybugs (n=5) and found them to have 2, 4, 5, 8, and 9 spots, you would calculate the average number of spots on a ladybug to be (2+4+5+8+9) ÷ 5 = 5.6 spots. Based on these observations, we might say a 'typical' ladybug has about 5.6 spots.

Averages are one of the most commonly used tools for analyzing data. By comparing averages from different situations, conditions, or experimental treatments, you can get an idea of trends or patterns which might help you answer your experimental questions. There are statistical tests which allow you to formally determine if the averages for two or more groups are different from each other.

3. What is a standard deviation?

A standard deviation is a number which gives you an idea of the spread of values which surrounds your average. An average of 5.6 spots on a ladybug could come from a sample of five ladybugs having 2, 4, 5, 8 and 9 spots, or it could come from a sample of five ladybugs having 5, 5, 6, 6, and 6 spots. The spread of values in these two cases is quite different; the first example will have a larger standard deviation (2.88) than the second (0.55). Often data are summarized as the average "plus or minus" the standard deviation: 5.6±2.88 or 5.6±0.55 for the two samples above.

The standard deviation is basically the average distance from each of your observations to the average (the standard deviation is a little higher than this, actually, because the farther-out data points are weighted heavier than those very close to the average). You can calculate the standard deviation by hand using formulas available from

your lab instructor or in a statistics textbook. Microsoft Excel can also calculate the standard deviation of a range of numbers.

4. What is a standard error?

Standard error is very similar to standard deviation; it is a value you can use to get an idea of the spread of values surrounding your average. However, standard error takes into account the sample size (n) of your data. The more data points you have in your sample, the smaller your standard error will be. For example, if you have a sample size of 5 ladybugs, with 2, 4, 5, 8, and 9 spots, the standard deviation is 2.88. If you have a sample size of 10 ladybugs, with 2, 2, 4, 4, 5, 5, 8, 8, 9, and 9 spots, the standard deviation is quite similar, 2.71. However, the standard error for the 5-ladybug sample (n=5) is 1.29, while the standard error for the 10-ladybug sample (n=10) is only 0.86. A 100-ladybug sample (n=100) with the same pattern of values has a standard deviation of 2.59, and a standard error of only 0.26.

Standard error is commonly used in biology; you can use standard error information to quickly predict if two averages are significantly different or not. If you look at the range of values from one standard error below an average to one standard error above the average, and the ranges for two different averages overlap, the averages are probably not significantly different from one another. If the ranges do not overlap, though, chances are good that if a statistical test is performed, the averages will be significantly different. Scientists often indicate standard error with error bars on their graphs; this can give you a way to quickly detect visually if ranges overlap.

Standard error is the standard deviation divided by the square root of the number of observations in your sample (n, or the sample size). Microsoft Excel does not calculate this for you with a ready-made formula, but you can make an Excel formula to do it yourself. See your lab instructor if you have questions.

5. What are the common types of statistical analyses used in Intro Bio?

Currently, Intro Bio labs at Carleton use the two-sample Student's t-test (in Bio126) and the χ^2 test (in Bio 125). The Student's t-test is used to determine if two averages are significantly different or not, and the χ^2 test is used to determine if two distributions of numbers are significantly different or not.

6. When do I use a Student's t-test?

A Student's t-test is appropriate when you want to find out if two sample averages are significantly different. You can only compare two averages with this test; the more samples/observations you have for each average, the stronger the test will be. This means the smaller your sample sizes are, the harder it is to prove two averages are different. You might use this test to compare the average number of spots on ladybugs in Minnesota to the average number of spots on ladybugs in Hawaii (or some other pleasant research destination). The end result of a t test is a number called t, the t statistic, or the t-value. A larger t-value represents a greater difference between the averages, and a greater likelihood that they are statistically significantly different.

7. When do I use a χ^2 test?

A χ^2 test is appropriate when you want to find out if two distributions of numbers are significantly different. If you find, for example, that in Minnesota there seem to be a lot of ladybugs with 2-5 spots, and a lot of ladybugs with 8-10 spots, but very few with 6-7 spots, then talking about an average number of spots might not represent your data very well. If you wanted to compare these ladybugs with some in Hawaii, to see if they have the similar odd spot pattern (either few or many spots, but not a medium number of spots), you would need to compare your results using a χ^2 test. The end result of a χ^2 test is a number called χ^2, the χ^2 statistic, or the χ^2-value. A larger χ^2-value represents a greater difference between the distributions of numbers, and a greater likelihood that they are statistically significantly different.

8. How are results of statistical analyses presented?

Often, a scientist will state in the text of the Results section whether two sets of results are significantly different or not; the details of the test results are usually presented parenthetically. For example, you might report "The average number of spots on ladybugs in Minnesota is not significantly different from the average number of spots on ladybugs in Hawaii ($p>0.05$, $t=1.3$, 5 d.f.). The three quantities in parentheses

represent, respectively, the p-value, test statistic value (in this case, the t-value from the t-test), and the degrees of freedom.

Note that the term "significant" has a very particular meaning in the context of scientific writing; if you want to express great difference but have not done a statistical analysis, choose the word "substantial" to describe the difference.

9. How do I know whether my results are significantly different or not? What is a p-value? How do I know what a p-value means?

   A probability value, or p-value, is the common language of statistical test results. Scientists have agreed on this common language, and understand what p-values represent, even if the particular statistical test another scientist uses is completely unfamiliar. A p-value is a proportion, ranging from zero to one, and represents the likelihood that the data you are comparing are not significantly different. A p-value of 0.95 means there is a 95% chance that your data look the way they do due purely to random events, not because you've identified a real difference. A p-value of 0.01 means that there is only a 1% chance that your data can be explained by random events. In biology, it is *generally* agreed on that a p-value less than 0.05 (less than 5%) is "significant" and indicates a distinct, non-random pattern to your data (the particular pattern depends on the particular test you use).

   P-values are rarely reported directly, as in "p=.0142." They are generally reported, particularly when significant, as "$p<0.05$," "$p<0.01$," "$p<0.001$," and occasionally "$p<0.0001$." Smaller p-values are rarely differentiated further than this (saying a p-value is less than 0.01% is already an extremely strong statement of significance). This shorthand for reporting p-values makes it easier for scientists reading the paper to get a quick sense of how significant the results are. A scientist might have the following ideas attached to p-values: "$p<0.05$ indicates a definite pattern worth looking at; $p<0.01$ is a strong, convincing statistic, and $p<0.001$ is quite conclusive (and impressive)." However, thoughts like this will vary depending on the particular field in biology; in some behavioral or field studies, $p<0.05$ may be considered extremely strong evidence for a significant pattern in the data. In other disciplines, p-values may have different, agreed-upon meanings.

   In summary, generally a p-value below 0.05 in biology will mean that the results you're comparing are significantly different. A p-value above 0.05 means you cannot claim the results are different (although you can describe trends and call for more studies to see if the trends hold up with larger numbers of organisms).

10. How do I determine a p-value?

    Once you have calculated the statistic for your test (t-value, χ^2 statistic), you can look up the p-value on a special table (called a "critical values" table) for that statistic. These tables are available in statistics reference books and online. You will need to know the degrees of freedom for the statistic you calculated in order to use these tables.

11. What are "degrees of freedom?"

    The "degrees of freedom" for a statistical test takes into account the sample size of your data. The more pieces of data you are using to describe your results, the stronger the test will be; a higher number of degrees of freedom is associated with a stronger test. The degrees of freedom is a positive number, almost always an integer. The degrees of freedom is determined differently depending on the statistical test used.

The Results Section II: Summarizing Results in Tables and Figures

Overview

Most Results sections contain data in tables or figures (figures may consist of diagrams, maps, photos, or graphs). Sometimes your instructor will tell you how to present your data; other times, you will need to decide how the data can be most clearly and effectively presented. You want to make sure the tables or figures show the main patterns in your data effectively. You should not present the same data in multiple figures and/or tables unless you are showing a unique pattern with each.

Tables must have a table caption above the table, which includes the title of the table and any necessary explanatory information which allows the table to be understandable on its own (without the text of the Results section). In tables, each column should represent a different type of variable or measurement which was made, and each row should represent a different treatment you want to compare. You want to be able to easily compare results for a given type of test or observation by looking down a column, not reading across a row. Tables are good for presenting results which (1) are not easily summarized in the text of the results section and (2) are not showing quantitatively related trends, which might be better presented in a figure.

Figures must have a figure caption below the figure, which includes the title of the figure and any necessary explanatory information which allows the figure to be understandable on its own (without the text of the Results section). On a graph, the independent variable should be plotted on the horizontal x-axis; this variable is often something you know before you run the experiment. The dependent variable should be plotted on the vertical y-axis of a graph; this variable is usually what you are measuring, which depends on the value of the independent variable.

FAQ

1. How do I know whether to make a table or a graph?
2. Do I need to make a table of my data in addition to my graph?
3. What belongs in a table or figure caption?
4. How much methods information needs to be in my table or figure caption?
5. Do I number my figure or table if I only have one?
6. Do I number my tables separately from my figures?
7. When should I use a bar graph versus a line graph versus a scatter plot?
8. When do I use a line of best fit?
9. How do I make a bar graph?
10. How do I make a scatter plot?
11. How do I make a line graph?
12. What is a semi-log plot?

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1. How do I know whether to make a table or a graph?

   If your data form a clear visual pattern when they are graphed, you will probably want to use a graph. It is easier for a reader to understand a pattern when it is presented visually in a graph. If there is no clear visual pattern, and/or you are trying to summarize a variety of data, a table may be more effective. Keep in mind that there are times when results can be successfully presented in the text of your Results section without the use of a table or a graph.

2. Do I need to make a table of my data in addition to my graph?

   No. In fact, you should not present the same data in more than one format, unless you are trying to make a different point with each figure/table.

3. What belongs in a table or figure caption?

   The table or figure caption should start with the figure number or the table number, e.g. "Table 1." The first phrase of your caption should be the figure or table title. This is not a complete sentence, but a descriptive noun phrase with only the first word capitalized and a period at the end. Your caption needs enough information that a reader can understand and interpret it for themselves without having to refer to the text of your Results section. Make sure the different data sets you are displaying are clearly described, as well as clarifying any potentially confusing axis labels. You may include information about the symbols for different data sets in a separate legend box on the graph if that seems clearer. Include in the caption the scientific names of any

organisms used to produce the figure. If you are reporting or displaying averages, be sure to provide the sample size for each in the caption. You will need to make sure any abbreviations you use are defined in the caption. If you have a graph with error bars, you need to specify what those represent (the whole range of your data? standard deviation? standard error?).

4. How much methods information needs to be in my table or figure caption?

   You don't want to rehash your Materials and Methods here, but you want to provide information which will be relevant to someone interpreting your table or figure. This might include the number of organisms you looked at, the number of times you repeated the experiment, the difference between different trials, or the temperature at which you collected your data. In some cases, these factors might be irrelevant to the data, in which case you would not need to include them in the caption.

5. Do I number my figure or table if I only have one?

   Yes; always put a number on your figures and tables, even if there is only one. You will refer to your figure or table by number.

6. Do I number my tables separately from my figures?

   Yes; if you have one table and one figure, they will be Table 1 and Figure 1, respectively. (They would not be called Table 1 and Figure 2.)

7. When should I use a bar graph versus a line graph versus a scatter plot?

   A bar graph has bars coming up from the x-axis, and the height of the bars represents the relative value of the dependent variable. A scatter plot is just dots, in one or more series or observation sets, plotted on a graph. A line graph shows different series of dots, and the dots of each series are connected by a line. A bar graph is used when you want to represent data which have a discontinuous independent variable. Use a line graph or a scatter plot to display data which have a continuously variable independent variable. Connect dots on a scatter plot (to form a line graph) only when you have some reason to believe there is an overall, clear pattern which allows you to guess at the values between your dots. Most three-dimensional graphs, Pie charts, bubble graphs, and other types of graphs are considered inappropriate for scientific papers.

   Time (even if you take measurements only every ten minutes) is a continuously varying independent variable, and so you would use a line graph to depict it on the x-axis. Different types of organisms would be discontinuous, so if you collected the same type of data for several different types of organisms, you would use a bar graph to show your results. If you have an independent variable, and you aren't sure what order the data should go in, that's a good indication that the variable is discontinuous. You can also have data which are numerical but not continuous. If you want to show how many ladybugs you found with one spot, how many had two spots, etc, you might find it clearest to use a bar graph, with "Number of Spots" on the x-axis and "Number of Ladybugs" on the y-axis. In this instance, there is no such thing as 1.5 spots, so a line graph would be misleading.

8. When do I use a line of best fit?

   If you are plotting values which you have some reason to believe are exponentially, logarithmically, or linearly related, you may choose to represent them with a best-fit line. Generally, do not a line of best fit unless you know something about why it might be appropriate. You can draw a best-fit line on a graph by hand using a ruler, or Excel can calculate the best fit line for you. Search on "trendline" in Excel for help with this. If you double-click the trendline, you will find options for adding the equation of the line to your graph, which may be helpful.

9. How do I make a bar graph?

   Always construct a bar graph so that the bars go up from the x-axis. Bar graphs with horizontal bars are extremely rare. If the bars on your bar graph represent averages, consider adding error bars which represent the standard error of your data.

   In Excel, you will probably want to construct your data table such that the x-axis categories or values are in a column together. To the right of that column, add columns containing the dependent variable data you collected, one

column for each set of data or observations you have. (You may have only one column of dependent data, or you may have multiple columns; for example, you might collect data on the number of female ladybugs with one spot, two spots, etc., which might go in one column, followed by a column with data for male ladybugs.) You can search for help on "bar chart" and "error bar" for help in constructing this sort of graph. In Excel, it is possible to change the appearance of the lines and bars on your graph to make the patterns in your graph as clear as possible. Try double-clicking on the element you'd like to change, and often an appropriate dialog box will appear.

10. How do I make a scatter plot?

In Excel, you will probably want to construct your data table such that the x-axis values are in a column together. To the right of that column, add columns containing the dependent variable data you collected, one column for each set of data or observations you have. (You may have only one column of dependent data, or you may have multiple columns; for example, you might collect data on the concentration of a chemical over time during a reaction, and test this under different conditions (like temperature). Time might be your x-axis variable, and you might have a different column for each condition you looked at.) You can search for help on "scatter chart" in Excel to construct this sort of graph. In Excel, it is possible to change the appearance of the symbols on your graph to make the patterns in your graph as clear as possible (making the symbols larger is often helpful). Try double-clicking on the element you'd like to change, and often an appropriate dialog box will appear.

11. How do I make a line graph?

See "How do I make a scatter plot?" above. In addition, make sure you do NOT choose "line chart" as the chart type in Excel; this unfortunately-named graph type will incorrectly represent your x-axis as categories, not numerical values. You can make a correct line graph by choosing "scatter chart" and connecting the dots with a line (a choice of sub-type under scatter chart).

12. What is a semi-log plot?

A semi-log plot is a special type of graph in which one axis has numerical values which are not linearly arranged; instead, they are arranged logarithmically, so that the distance from 10 to 100 is the same as the distance from 100 to 1000. This type of graph is extremely useful when you are trying to display two variables which are logarithmically related: the points on a semi-log plot will form a straight line. Without a computer, a straight line is much easier to fit to a set of points than a curved, logarithmic line is; all you need is a ruler. A semi-log plot is also useful when one of the variables under consideration shows extreme variation, because a wide range of values can be placed on one graph without losing too much specificity.

Example Figures

Here are two figures from scientific papers published by Carleton faculty and alums. See the examples after "The Results Section III" for descriptions of these figures.

From McKone et al. 2001:

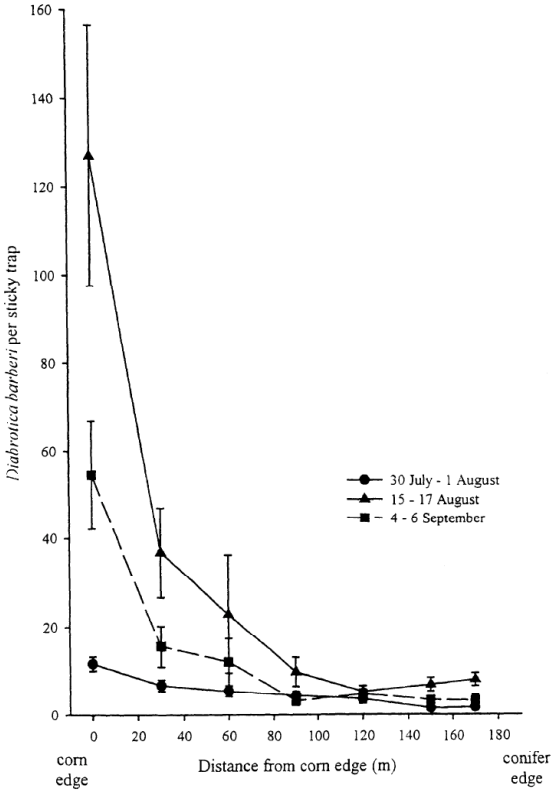

Figure 2. Number of* Diabrotica barberi *from 56 sticky traps exposed for 48 hours at three times during the season. Averages across eight transects (Fig. 1) are shown. Bars are ±1 SE.

from Sawai et al. 2003:

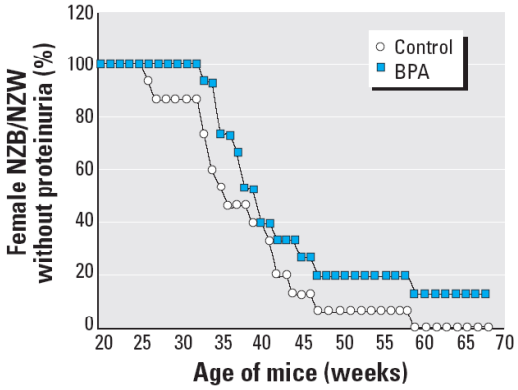

Figure 5. Development of proteinuria in 5- to 6-week-old female NZB/NZW mice fed PBS (n = 15) or BPA (n = 15) daily for 7 days.

The Results Section III: Summarizing the Results in Written Description

Overview

The Results section answers your reader's question: "What were the findings?" (Day 1994). The text of the Results section is where you summarize any data not present in tables or figures, and where you describe the patterns in your results, referring explicitly to your tables and figures. While you do not interpret or explain your results in this section (that happens in the Discussion section), you can use this section to focus your reader's attention on the aspects of your results which are most important to you. You will need to use skills in persuasive writing and argument as you make choices about what to summarize and how to summarize it. Many writers choose to put this section together after they have written their Materials and Methods section, before they write their Introduction and Discussion sections. However, you may find that as you develop your Discussion section, you decide to revise the Results text to emphasize aspects of your results which better support your conclusions.

FAQ

1. What verb tense should I use in presenting my Results?
2. Should I use multiple paragraphs in my Results section?
3. Can I use sub-headings in my Results?
4. How do I describe the general patterns in my results? Aren't those obvious from the graphs?
5. How do I report results of statistical analyses?
6. Do I need to include my statistical calculations in my Results section?
7. How do I relate my results to the relevant figure(s)/table(s)?
8. My Results section seems really short. What am I forgetting?

---

1. What verb tense should I use in presenting my Results?

   Because you are describing the results of experiments you performed, much of this section is likely to be in past tense.

2. Should I use multiple paragraphs in my Results section?

   Yes, unless you have only one result to describe. Even if the paragraphs are fairly short, multiple paragraphs help your reader to separate the main points you are trying to get across.

3. Can I use sub-headings in my Results?

   The use of sub-headings is acceptable if it clarifies your ideas for the reader. If your Results section is extremely short, sub-headings probably are not necessary (a sub-section with only one or two sentences seems inappropriate).

4. How do I describe the general patterns in my results? Aren't those obvious from the graphs?

   While the patterns in your results may seem obvious to you from your figures, your job is to help the reader (for whom this is all new) understand what you think is most important about your results. The text of your results section should be understandable without relying on your figures, and at the same time should do more than describe each line or point in your figure. Think of this section as an opportunity to generalize your results (Penrose and Katz 1998) rather than to list them all specifically. You can always make your generalization stronger by referring to specific results, but listing all of them in the text makes the reader work too hard.

   In addition to answering the general "What were your findings?" question, you can think of this section as answering more specific questions, like: What is similar? What is different? In what way

do things differ? How substantial is the difference (is it significant)? What happened over time? You may find it helpful to generate questions like this which are appropriate for your particular study, and make sure the Results section answers each of them (Pechenik 2001).

5. How do I report results of statistical analyses?

   The specifics of a statistical analysis are generally presented parenthetically in the text of the Results section. In the sentence, be extremely clear about what was being compared, report whether the difference was statistically significant or not, and include the test statistic, degrees of freedom, and p-value in parentheses. Here is an example, from a paper in which a *G*-test of independence was the statistical test used: "The rate of predation on the plain brown replica (26%) did not differ from that of the brown pattern mimic (27%; G = 0.03, df = 1, P>0.50)." (Hinman et al. 1997).

6. Do I need to include my statistical calculations in my Results section?

   No. You should merely report the results of the statistical test as described in Results FAQ #5 above. You do not need to include your calculations anywhere in your report.

7. How do I relate my results to the relevant figure(s)/table(s)?

   Most commonly, figures and tables are referred to parenthetically. While it might be tempting to write "Figure 1 shows..." it is more useful to the reader if you put the important summary information starting at the beginning of the sentence, and use a parenthetical "(Fig. 1)" to refer readers to the relevant figure which supports the data summary you've just made in the text.

8. My results section seems really short. What am I forgetting?

   Remember that you need to describe all the results from your experiments—this means including information about any results not presented in figures and tables, as well as fully describing your figures and tables. (Imagine describing the figure on the phone to someone who can't see it, and you'll get the idea of how you need to describe figures.) You also need to report the results of any statistical analyses. Finally, make sure that somewhere (here or in your Materials and Methods section) you have defined any abbreviations you are using, and explained what they represent.

   Do not try to pad your results with calculations or explanations of your data. You do not need to include calculations in your report. Save all explanations for the Discussion section of the report.

   Realize that most published scientific papers represent months of research, rather than a few hours' worth of work, so you can't expect to have a comparable amount of text in your Results section.

Example Results Sections

Here are excerpts from the Results sections of scientific papers published by Carleton faculty and alums. These descriptions refer to the figure examples in the previous section.

From McKone et al. 2001:

Within McKnight Prairie, the rate of capture of *D. barberi* in sticky traps was strongly dependent on proximity to the boundary with corn (Fig. 2). The effect of position was highly significant for all three sample periods (Kruskal-Wallis test, df = 6, $p < 0.001$). The edge effect was most pronounced when the *D. barberi* population peaked in mid-August, at which time there were approximately 18 times as many beetles captured at the corn edge as at the locations farthest from the edge.

From Sawai et al. 2003:

To analyze whether in vivo BPA exposure modulates the course of lupus, we fed BPA to three separate groups of 5- to 6-week-old female NZB/NZW mice for 7 days. Each group consisted of five BPA-fed mice and five control mice. In each of the three experiments, a control NZB/NZW mouse was the first to develop proteinuria. Overall, female BPA-treated NZB/NZW mice showed an average delay of 7 weeks in the onset of proteinuria compared with untreated controls (Figure 5). The earliest onset of disease symptoms was at 26 weeks in a control mouse, whereas the earliest BPA-treated mouse to develop proteinuria was 33 weeks of age. On average, the mice treated with BPA remained symptom-free for 45 weeks compared with 38 weeks in control animals. Two of the BPAfed mice showed no signs of proteinuria at 72 weeks of age.

The Discussion Section

Overview

The Discussion section answers your reader's question "What do these findings mean?" (Day 1994). This section is often written after or in conjunction with the Introduction, after the Materials and Methods and Results sections. The Discussion section is very important, because it is here that you explain the reasons for your results and describe what you think the results mean. Re-summarize your results as needed to remind the reader what you're discussing, and refer to specific results to support your ideas.

In this section, you should provide the implications of your results; in what way do your results help fill the gap of knowledge in the field (the gap your original question was trying to address)? The Discussion section is also the place to discuss any errors which may have systematically affected your results, making the patterns you observed misleading. You should also include ideas about what future studies might help shed further light on your question, or what new questions and studies are suggested by your results. The Discussion section is where the sophistication of your understanding really shows; it is also the section which allows for the most creativity on your part, since you are thinking broadly about the implications of your results. The Discussion section is often structured like a pyramid, starting with a very narrow focus on your specific results and broadening to show how they fit in the larger context.

In the Discussion, you will be using your results as evidence to support your ideas. You will need to draw on good writing skills to present your evidence and conclusions as convincingly as possible. You will want to refer to specific results in your Discussion, as you try to make specific points; think about how to strengthen your arguments and make them as clear as possible.

FAQ

1. What verb tense should I use in presenting my Discussion?
2. Should I use multiple paragraphs in my Discussion section?
3. How long should my Discussion section be?
4. How do I know what conclusions I can draw from my results?
5. What do I do if my data seem to contradict previously published results?
6. I don't fully understand my results; they don't make sense according to what I've learned in biology classes. Can I just explain why our methods were flawed and blame our results on error?
7. How do I know if our results were affected by human error, and when should I discuss that?

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1. What verb tense should I use in presenting my Discussion?

   You will probably need to use a wide variety of tenses in your Discussion: past tense when referring to your results, present tense when explaining them and writing about their implications, and future tense when you are writing about potential studies.

2. Should I use multiple paragraphs in my Discussion section?

   Yes. This section will require you to look at your results at different levels, from explanation to implication to future work. One paragraph will not be sufficient.

3. How long should my Discussion section be?

   This section will vary in length, so there isn't a blanket statement that will answer this question. If you've written two or three short paragraphs and feel like you've covered everything, I would suggest pushing yourself to delve deeper into the material and see if there aren't some interesting aspects of the data you're missing. Your job in this section is to explain your results, describe how they fit into existing scientific literature, and propose additional studies that might help give you a clearer picture of what's going on (either for the questions you set out asking, or new questions that are coming out of your results). While you should explore the data and their implications, you should still be very clear and direct in your writing style; if you've put together five pages of text for the Discussion section, it might be a good idea to critically evaluate what you've written, to make sure it is all clear and on-topic.

4. How do I know what conclusions I can draw from my results?

This is a bit tricky; you want to make sure your ideas are as directly supported by the data as possible. You will want to give a carefully reasoned explanation of what you are basing your ideas on: which specific parts of your data, what previous research, what general biology knowledge? You should not make grandiose statements about truth based on your results, but it is good to propose new explanations and ideas. Just make sure you state them as possibility rather than fact, and ground them solidly in ideas that are already accepted.

5. What do I do if my data seem to contradict previously published results?

   Do not panic, and do not discard or disregard your data. Look at the patterns in the data and try to come up with some well-reasoned explanations for the differences. If you get stuck, talk to your lab instructor or TA to get some ideas.

6. I don't fully understand my results; they don't make sense according to what I've learned in biology classes. Can I just explain why our methods were flawed and blame our results on error?

   No. Do not discount your results and claim that since the data were collected by students, they are bound to be flawed. Ask your lab instructor if you are doubtful about some of your results; they may have suggestions for you. Generally, it is best to treat the data as if they are correct, and try to come up with a biological reason the results don't meet your expectations. Respect your data. Think about what other factors might be influencing your results. A careful analysis is much stronger than an off-hand "human error caused it to be wrong." Human error can be a factor, but you need to evaluate the possibility carefully. If you really believe human error caused your results, you need to have some evidence that human error could cause the particular pattern of results you're seeing, and describe the potential error specifically.

7. How do I know if our results were affected by human error, and when should I discuss that?

   You can be sure that there was some human error in our results. There is probably some human error in most results; we worked to minimize it, as all scientists do. The only time you would discuss human (or any other) error is if you thought it had systematically affected your results in an important way. Here's an example of an appropriate inclusion of error in a lab report Discussion: "We forgot to keep our seeds moist for the first three days of our experiment, which may have caused our seed germination times to be artificially lengthened." (In a research lab, you would probably repeat the experiment rather than report on such a result.)

The Acknowledgements Section

Overview

The Acknowledgements section is very short, usually only one or two sentences long. In the Acknowledgements, you thank any individuals who helped you with your experiments and you thank any funding source for supporting the experiment. Generally, colleagues are referred to by their first and last names, with no title (except in the case of medical doctors, who are referred to as Dr.). If you feel it is important to use a title for people in your Acknowledgements, make sure you are using the proper title: in this case, people with a Ph.D. should be referred to as "Dr.," not "Mr." or "Ms."

Example Acknowledgements

Here are two Acknowledgements sections of scientific papers published by Carleton faculty and alums. They represent the variety you'll find in this section.

from Hinman et al. 1997:
Note that the order of the first five authors was determined by throw of dice. B. Brodie generously provided advice and guidance, and B. Ostertag helped us in the field. We thank B. Brodie, F. Janzen, H. Landel, B. Ostertag, and M. Rand for helpful comments on an earlier version of the manuscript. The staff and facilities of La Selva and of the Organization of Tropical Studies made this project possible. Funding was provided by Carleton College; support from President Stephen R. Lewis Jr. is particularly appreciated. We are grateful to the members of the 1994-1995 course in Tropical Rainforest Ecology at Carleton College for assisting in the construction of replicas and for reading *Catch a Star* to the Snake Women.

from Sawai et al. 2003:
We thank M. Muehlegger, M. Finnerty, M. Chaurushiya, A. Park, and N. Scott for their help with these experiments.

This work was supported by National Institutes of Health grant R15 AI50595-01 and a Faculty Development Endowment grant from Carleton College.

The Literature Cited Section

Overview

The final section in your paper is the Literature Cited section, where you list your references. In a scientific research article, only papers and books which are cited in the text are listed in the Literature Cited. If you used a book to help you understand but did not use specific information from it in your paper, you would not include it in the Literature Cited. This section should be written after citations are placed in the text; if you are using the reference-managing software EndNote, the Literature Cited can be created as you insert references. See Charlie Priore, the Science Library Liaison, with questions about getting EndNote installed on your personal computer (available free).

You should check with your lab instructor to find out what citation format to use. In Bio 125, *American Naturalist* format is required. You can use any recent *American Naturalist* paper as a model for your in-text citation format and Literature Cited format.

FAQ

1. What is the basic *American Naturalist* format?
2. How do I cite the lab manual?
3. Why do some of the in-text citations of the *American* Naturalist paper contain the phrase "et al."?
4. Some authors seem to cite themselves frequently; isn't that egotistical?

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1. What is the basic American *Naturalist* format?

   Here is a summary of the *American Naturalist* style for journal articles:

   FirstAuthorLastName, A. B., C. D. SecondAuthorLastName, and E. F. ThirdAuthorLastName. YEAR. Title of journal article with first word capitalized and subsequent words lower case. Title of Journal with Main Words Capitalized vol#:firstpage-lastpage.

   The Literature Cited section of this guide uses *American Naturalist* format, if you would like examples. Note where the periods, spaces, and other punctuation marks are. All but the first line of each entry is indented (in Word, search for help on "hanging indent"). The first author is listed last name first, but subsequent authors are listed initials first. If there are more than three authors, additional authors may be listed in the same format as the second author above. The year should be the year of publication, not the year the article was submitted to the journal. If there are scientific names in the title of the journal article, these should be italicized and the genus name should be capitalized. Do not include the issue number if one is given.

2. How do I cite the lab manual?

   Cite the lab manual parenthetically in the text like this: (Carleton Biology Department 2006). See the Literature Cited listing of this guide for the proper format (for the Bio 125 manual) in that section (listed alphabetically by the "C" of Carleton).

3. Why do some of the in-text citations of the *American* Naturalist paper contain the phrase "et al."?

   If a paper has two authors, list both their last names inside the parentheses with the year of publication. If a paper has more than two authors, list only the first author followed by the words "et al." and then the year of publication. "Et al." is short for the Latin phrase "et alia," which means "and others."

4. Some authors seem to cite themselves frequently; isn't that egotistical?

   It is actually quite common for scientists to cite themselves. Scientists might work with the same experimental organism or system for many years, and their work naturally builds on work they did last year or several years ago. The work they have previously published has become part of the base of knowledge in the field, and they would be remiss not to cite it.

Revising and Finishing

We encourage you to plan for time to revise your work. You might find it helpful to read your paper out loud, ask a friend to read your paper and make comments, or take it to the wonderful folks at the Write Place and discuss it with them. If your paper is well-written, other students should have no trouble understanding it (perhaps with the exception of the Materials and Methods section).

As you revise your paper, realize that there are a few cautions which can apply to any section of your paper. Before turning your paper in, check for the following:

Each section of the lab report (except the title) should be labeled ("Abstract," "Introduction" etc.). In some journals the Abstract is not labeled as such, but it is a good idea nonetheless.

Double-space the text in your lab report, so your instructor has room to write comments.

You should not personify anything in the lab report (e.g. data can't "want" things).

You should make no value judgments about your data, including stating that some data are "good" or "bad." You should not express a personal desire to see a particular result, even if it is expected.

When writing genus and species names, be sure to follow convention: the genus and species are both italicized, and only the genus is capitalized: *Homo sapiens*. If you refer to the same species later, you may abbreviate the genus name (*H. sapiens*). It is a good idea to write out the genus name the first time it is used in each section of the lab report.

Define all abbreviations in your report the first time you use them.

You should use the following words properly. In fact, it is a good idea to "search" in your paper for these terms and check that you have used them correctly before you turn the paper in.

significant: This word has a particular meaning in scientific writing which differs from that in other writing; "significant" is *only* used to refer to a difference which has been tested to be statistically different. If you mean "large," or "important," try substituting "substantial."

data: This word is only plural; the singular form of this word is "datum."

affect/effect: Affect is usually a verb, and effect is usually a noun; look up the words in a dictionary if you are unsure.

absorbency/absorbancy: These terms have nothing to do with spectrophotometry; only "absorbance" is used in this context.

larva/larvae: Larva is the singular form of the word; larvae is plural.

variance: This has a specific statistical meaning; use it only if you are sure you know how to use it correctly.

variable/different: If something is variable (or "varies," that means that it has a wide range of numbers which describe it. This is not the same thing as saying two things are different from one another. The word "variable" is commonly misused in lab reports to mean "different:" use "different" if that's what you mean.

differentiation: Differentiation is the process of becoming different; use this term carefully.

Finally, your paper should be stapled before you turn it in; unless your instructor specifies otherwise, no folders are necessary (these often make grading difficult). In some cases, you will be required to attach drafts of your paper to the final report; make sure you attach these as requested.

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