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 beginning 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. For each section, after the FAQ there are model examples from scientific research papers published by Carleton College faculty and alums. Read through these 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. Your report should use cohesive paragraphs with clear topic sentences. Your story should be easy to follow, with transitions that allow for a logical narrative flow.

While you'll use the same writing techniques for a lab report that you use in other classes, the format of a primary research article is rather formulaic by comparison. 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. There are sometimes journal-specific variations, such as a combined "Results and Discussion" section, a shift of the Materials and Methods section to the end of the paper, or the addition of a simplified summary or graphical Abstract, but these basic components are

very familiar to all biologists. Biologists have a good understanding of what sort of information can be found in each section. 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 the 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.

General Style Considerations

You will want to write as clearly and directly as possible. Scientific papers use formal language, so you shouldn't use colloquialisms, emotional language, or impassioned, dramatic phrases. However, you should not try to "sound like a scientist," particularly if you think of scientific writing as stilted and difficult to follow! In terms of formatting, typically you should write in a single column (rather than two columns on the page) for ease of instructor comments. This Lab Report Guide is written using *American Naturalist* citation style, and includes specific instructions for following this format. Unlike other fields, each journal in biology has its own citation style. Your lab instructor will tell you what citation format to follow; be very careful to pay attention to the details associated with that style. Your lab instructor may also provide you specific instructions about using a title page, line spacing, font size, length, etc.

The Parts of a Scientific Paper

Title

Overview

The title is a specific, informative summary of the main point of your study. It should be clear what you were studying (e.g. it should include the name of the organism if relevant), what you were comparing, and (if possible concisely) the main result. 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. Unless otherwise noted by your lab instructor, you should include your name on your paper below the title.

Example Titles

Note the level of detail present in these 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.

Grazing maintains native plant diversity and promotes community stability in an annual grassland (Beck et al. 2015)

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

Mechanisms of interspecific competition that result in successful control of Pacific mites following inoculations of Willamette mites on grapevines (Hougen-Eitzman and Karban 1995)

Mechanical noise enhances signal transmission in the bullfrog sacculus (Indresano et al. 2003)

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

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)

Ly6h regulates trafficking of alpha7 nicotinic acetylcholine receptors and nicotine-induced potentiation of glutamatergic signaling (Puddifoot et al. 2015)

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), the explanation for those findings, 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 that has already been done. For some statements that 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 numerical result. 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?

   Generally, no; there may be exceptions.

Example Abstracts

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 Johnston et al. 2006:
Reproductive success is a critical measure of an organism's fitness. Determining reproductive success in vertebrates is confounded by the concealed mechanism and timing of fertilization (e.g., sperm competition and storage). To assess the relationship between observed mating behavior and reproductive success in the central Asian tortoise, *Testudo horsfieldii* Gray, 1844, we determined individual genotypes from a captive colony of adults and their offspring. We constructed a size-selected genomic library from *T. horsfieldii* and screened for polymorphic microsatellite markers. The screen resulted in identification of two novel microsatellite regions. Cross-species amplification of microsatellite markers using primers developed for the bog turtle, *Glyptemys muhlenbergii* (Schoepff, 1801), resulted in isolation of three additional polymorphic microsatellites for *T. horsfieldii*. The five loci, which have between 5 and 17 alleles and observed heterozygosities between 0.44 and 0.90, were used to determine the frequency of multiple paternity in the captive colony. We found evidence for multiple paternity in 27% of the clutches examined, as well as evidence for overwinter sperm storage and variance in adult male reproductive success. These data indicate that ample opportunity exists for sperm competition and female mate choice in *T. horsfieldii*.

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 MacCormick et al. 2012:
Aggression is ubiquitous, influencing reproduction through inter- and intraspecific effects in ways that reflect life-history strategies of species. In many social mammals, females remain in their natal group for life, whereas males emigrate and compete for rank in other social groups. Competition for rank is inherently risky. Therefore, it has long been hypothesized that risks of injury depend on an individual's sex, rank, and age in ways that maximize an individual's reproductive output. However, studies quantifying such risks have been lacking. We analyzed 20 years of long-term data on wounds among olive baboons (*Papio anubis*) in Gombe National Park, Tanzania. Males received significantly more wounds than female baboons, and both sexes received the most wounds at ages when they competed most intensely for rank. Immature females received more wounds than immature males in their natal groups, and immature females were more likely to be wounded by females than were immature males. Males in their natal group were wounded less often than immigrant males of the same age. The risk of wounding did not depend on rank in females but rose with rank in immigrant males. Lastly, females received significantly more wounds when cycling (not pregnant or lactating). This study is among the first to quantify the risk of injury for competitors of different sexes, ages, and ranks in social groups. Our results support the prediction that individuals target aggression toward present and future competitors and suggest that sexual coercion increases the risk of wounding in cycling females.

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.

From Nishizaki and Carrington 2015:
Organisms employ a wide array of physiological and behavioral responses in an effort to endure stressful environmental conditions. For many marine invertebrates, physiological and/or behavioral performance is dependent on physical conditions in the fluid environment. Although factors such as water temperature and velocity can elicit changes in respiration and feeding, the manner in which these processes integrate to shape growth remains unclear. In a growth experiment, juvenile barnacles (*Balanus glandula*) were raised in dockside, once-through flow chambers at water velocities of 2 versus 19 cm s^{-1} and temperatures of 11.5 versus 14 °C. Over 37 days, growth rates (i.e., shell basal area) increased with faster water velocities and higher temperatures. Barnacles at high flows had shorter feeding appendages (i.e., cirri), suggesting that growth patterns are unlikely related to plastic responses in cirral length. A separate experiment in the field confirmed patterns of temperature- and flow-dependent growth over 41 days. Outplanted juvenile barnacles exposed to the faster water velocities (32 ± 1 and 34 ± 1 cm s^{-1}; mean ± SE) and warm temperatures (16.81 ± 0.05 °C) experienced higher growth compared to individuals at low velocities (1 ± 1 cm s^{-1}) and temperatures (13.67 ± 0.02 °C). Growth data were consistent with estimates from a simple energy budget model based on previously measured feeding and respiration response curves that predicted peak growth at moderate temperatures (15 °C) and velocities (20–30 cm s^{-1}). Low growth is expected at both low and high velocities due to lower encounter rates with suspended food particles and lower capture efficiencies respectively. At high temperatures, growth is likely limited by high metabolic costs, whereas slow growth at low temperatures may be a consequence of low oxygen availability and/or slow cirral beating and low feeding rates. Moreover, these results advocate for approaches that consider the combined effects of multiple stressors and suggest that both increases and decreases in temperature or flow impact barnacle growth, but through different physiological and behavioral mechanisms.

From Nisi et al. 2015:
Historic, wide-spread destruction of native prairies in Minnesota was caused by conversion to agricultural land, disruption of disturbance regimes, and loss of key species. Attempts to restore tall-grass prairies have resulted in a new ecosystem type on the Midwestern landscape, with novel assemblages of both plant and animal species. The mammalian herbivore community, once dominated by bison, is now primarily comprised of white-tailed deer (*Odocoileus virginianus*), Eastern cottontail rabbits (*Sylvilagus floridanus*), and small mammals such as meadow voles (*Microtus pennsylvanicus*). The role of this assemblage of herbivores in restored prairies is not well understood. This study characterizes patterns of mammalian herbivory on five legume species in restored prairie in southern Minnesota. Legumes were sampled along transects that varied in their distance from the prairie-forest boundary and time since prescribed burning. Herbivore selectivity was determined for each legume species using an electivity index based on the total number of stems of each species and the percent of stems grazed. Herbivory was highly variable among legume species: *Desmodium canadense* was strongly preferred, *Dalea candida* and *Dalea purpurea* were moderately preferred, and *Amorpha canescens* and *Lespedeza capitata* were avoided. Both *Dalea* species and *Lespedeza* experienced increased rates of herbivory in burned sites. Avoided species were characterized by either low tissue nitrogen content or a high proportion of recalcitrant carbon relative to preferred species. These results suggest mammalian herbivores have an important functional role in prairie communities with potential consequences for community dynamics and the success of prairie restorations.

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.

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. The start of your Introduction should be directly relevant to your project; the first sentence often serves as a "hook" to draw in the reader—it indicates where you are going with this study and why this is a biologically interesting direction to go in.

As you describe what is known already, you will need to cite the work of other scientists; typically an Introduction section contains many citations. When you cite previous work, you should paraphrase information from previous studies, and summarize the relevant point or points those authors found; don't require your reader to look up the paper you've cited in order to understand your Introduction.

In most Introduction sections, it is also appropriate to describe what you think is going on biologically (your *hypothesis*, e.g. "the biochemical pathways for ladybug spot generation are affected by temperature") and what specific results you would expect to see if this reasoning is correct (your *predictions*, e.g. "ladybugs raised at 30°C will have more spots than ladybugs raised at 24°C"). To explain your predictions, you will likely need to describe something about the general approach or methodology you will be using. This description of your hypothesis and predictions helps prepare your reader to assess your results. It also can help you structure your Discussion section, whether your expectations are met or not.

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; do not follow this model unless you are specifically asked to do so.

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?
7. Should I quote other sources directly? How do I paraphrase?

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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 that 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. If other researchers have studied similar questions, it is important to set your work in the context of their results. Focus on the biology surrounding the questions you are asking. Some background on the organisms you are using may be important to understanding the experiments, but be selective so that only relevant information is included.

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 2018). 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? How do I paraphrase?

   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. For good examples of proper and improper paraphrasing of the same information, and suggestions for paraphrasing properly, see:

   http://www.plagiarism.org/article/how-to-paraphrase

   If you have questions about this, please talk to your lab instructor. We also encourage you to use the college web site for academic honesty resources.

Example Introduction and Introduction Excerpts

The citation formats in these papers are from the original publications; they are *not* in *American Naturalist* format.

From Hinman et al. 1997:
[This is the full Introduction section from the paper.]

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.

From Beck et al. 2015:
[This is the first paragraph in the Introduction section, in which the context for their question is set.]

Grassland ecosystems have experienced significant ecological changes due to anthropogenic increases in nitrogen (N) deposition (Vitousek et al. 1997, Bobbink et al. 2010), altered grazer assemblages and grazing regimes (Bakker et al. 2006, Fensham et al. 2014), and the invasion of exotic species (Shea and Chesson 2002, Harrison et al. 2006). These shifts in both bottom-up and top-down controls on plant communities have altered ecological interactions in grasslands and compromised the ability of grassland systems to support biodiversity and maintain ecosystem processes (Chapin et al. 2000, Gibson 2009). Thus, the maintenance of native biodiversity in grasslands will depend upon understanding how these systems respond to environmental change over time.

[This is the final paragraph from the same Introduction section, in which the authors describe the specific questions they are addressing.]

Although observational studies have suggested that cattle grazing in serpentine grasslands can reduce exotic grass cover, increase native plant diversity, and maintain habitat for threatened species (Weiss 1999, Safford and Harrison 2001, Gelbard and Harrison 2003, Harrison et al. 2003), the continued accumulation of N could reduce the ecological benefits of grazing (Pasari et al. 2014). Furthermore, the ecological effects of grazing and N deposition may vary through time and influence the temporal dynamics of serpentine grassland communities. We examined the interactive effects of N addition and cattle grazing on serpentine plant communities in California's largest serpentine grassland to address two primary questions: (1) What are the individual and interactive effects of N addition and livestock grazing on serpentine plant community composition? (2) How do N addition and grazing affect the temporal stability of serpentine plant communities?

From Jacobs et al. 2013:
[This is the first paragraph of the introduction, which sets the context for the study and identifies the general area to be investigated. Note that this journal format uses a numbered citation rather than a parenthetical author and year.]

Plant-pathogenic bacteria cause destructive diseases that limit crop production worldwide. Many Gram-negative phytopathogenic bacteria use a type III secretion system (T3SS) to inject effector proteins into host cells. These generally modulate host immunity and physiology for pathogenesis (1–4). Individual effectors rarely contribute measurably to virulence but rather function as a consortium (5). Because of their redundancy and subtle biological activities, the functions of individual type III (T3) effectors remain largely unknown.

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, making clear what you were comparing with each. Be aware that a Materials and Methods section is different from a protocol, the set of instructions you might find in your lab manual. 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. Can I just cite the lab manual, since I followed those methods?
6. How do I know how much detail to put into my Materials and Methods section?
7. How do I write about specific, specialized equipment or kits we used during lab?
8. 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?
9. 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?
10. What do I need to say about statistics 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 in some subdisciplines, 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.

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. Can I just cite the lab manual, since I followed those methods?

   Check with your lab instructor; they may ask you to re-write the information in your lab manual, which is in the form of a protocol, into a proper Materials and Methods section. It is also possible they will allow you to cite the manual directly or to report the procedures as personal communication (see the Literature Cited FAQ below).

6. 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 should include details about the methods if the way you did something systematically affected the results you saw. 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 final concentrations of components in solutions you used, but they will be less interested in volumes, and they definitely won't care that they were kept in a blue plastic bottle. Similarly, nobody needs to know how you labeled your materials or how the logistics of lab groups worked.

7. How do I write about specific, specialized equipment or kits we used during lab?

   Typically, you provide the name of the piece of equipment, kit, or supply you used and then follow with the name of the company you got it from in parentheses. You do not need to include this information for standard equipment like gel boxes or mechanical pipettes, but you should include it for more specialized resources that might not be found in most labs. If you aren't sure whether something fits this category, check with your lab instructor.

8. 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 state 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.

9. 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.

10. What do I need to say about statistics in my Materials and Methods section?

    State the statistical test that was used, specifying exactly what was being compared with the test. You do not need to include your calculations anywhere in your report. For common statistical analyses and numerical manipulations, you do not need to include equations, but in some fields this is an important part of your methodology to describe fully; check with your lab instructor.

Example Materials and Methods Section Excerpts

From Esch et al. 2013:
We used motion-detecting, infrared triggered cameras (Reconyx RM45, Reconyx Inc., Holmen WI) to record grazing intensity as the number of cow bites that occurred in 2010 in the grazed 5 × 5 m plot in each block. These cameras take one photograph per second when objects emitting a critical level of infrared radiation move within their field of view. We recorded cow bites per subplot (bites 12.5 m^{-2}) by recording each photograph in which a cow's mouth was within the boundaries of the plot and in contact with or in close proximity (~5 cm) to the vegetation. To avoid bias, cows were recorded on as either being on either the "left" or "right" side of the plot as seen in the image and identification of each side as either "fertilized" or "unfertilized" was later added to the data.

From Jacobs et al. 2013:
[This paragraph provides examples of describing specific kits and equipment used in a procedure.]

Tomato RNA was extracted and purified from pooled tissue samples ground in liquid nitrogen using an RNeasy minikit (Qiagen, Valencia, CA) following the manufacturer's instructions, except that initial flowthrough was applied to column twice. RNA was eluted in 30 μl RT-grade water. RNA purity and quality were evaluated on a NanoDrop (Thermo Scientific, Wilmington, DE) and an Agilent bioanalyzer picochip (Agilent Technologies, Santa Clara, CA), respectively. Samples with high quality (as defined by RNA integrity numbers greater than 8.0) and high purity (as defined by $A_{260/230}$ and $A_{260/280}$ of >1.9) were used for analysis.

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 Lowe-Power et al. 2018:
Plant growth conditions
Tomato seeds (wilt-susceptible cvs. Bonny Best and Money Maker, and quantitatively wilt-resistant breeding line Hawaii 7996) and tobacco cv. Bottom Special were sown in professional growing mix soil (Sunshine Redimix, Glendale, AZ) in a 28°C climate chamber with a 12 h photoperiod cycle. Tomato seedlings were transplanted 14 days postsowing into individual 4-inch pots containing ~80 g soil. Tobacco plants were transplanted after foliage diameter exceeded 1 cm. Transplants were watered with 50% Hoagland's solution.

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: (a statistics example)
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 Nisi et al. 2015:
For each plant surveyed, percent grazed was calculated by dividing the number of stems that exhibited herbivore damage by the total number of stems. *t*-tests were used to characterize differences in average percent grazed between burned and unburned fields for each species surveyed. Density of each legume species was calculated at the transect level and correlations were used to determine the relationship between legume density and grazing.

From Puddifoot et al. 2015:
Cell culture and transfection
HEKtsa cells were maintained at 37°C and 5% CO_2 in culture medium consisting of 10% fetal bovine serum (Omega), 1% penicillin/streptomycin (Mediatech), and 1% L-glutamine (Sigma) in low-glucose DMEM with 2 mM L-glutamine (Mediatech).

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%.

Analyzing Data in Preparation for the Results Section

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.

Depending on the type of data you collected, some of the information in this section of the FAQ may not be relevant to your report.

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 common types of statistical analyses?
6. When do I use a Student's t-test?
7. When do I use a χ^2 test?

8. How do I know what the results of my statistical test indicate? What does "statistical significance" mean? What is a *P* value? How do I know what a *P* value means?
9. How do I determine a *P* value?
10. 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.

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. An average has the same units as each observation. 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.

   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 that might help you answer your experimental questions. There are statistical tests that 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 (sometimes abbreviated SD) is a number that gives you an idea of the spread of values that surrounds your average. Like an average, a standard deviation is reported in the same units as each observation. 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 spots or 5.6±0.55 spots 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 (sometimes abbreviated SE) 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 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 treatments overlap, the averages are probably not statistically significantly different (see below for an explanation of statistical significance) from one another. If the ranges do not overlap, though, chances are good that if a statistical test is performed, the averages will be determined to 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 (see Figure 2 from McKone et al. (2001) below for an example).

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 it is available in a descriptive statistics option, or you can make an Excel formula to calculate it yourself. See your lab instructor if you have questions.

5. What are common types of statistical analyses?

The two-sample Student's t-test and the χ^2 test are commonly used. The Student's t-test is used to assess the difference between two averages, and the χ^2 test is used to assess the difference between two distributions of numbers. You'll hear both "ki square" and "ki squared" used, though "ki square" is more common, with the "ki" pronounced like in "kite."

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 different. You can only compare two averages with this test; you can't compare the averages from three or more treatments at once. The smaller your sample sizes are, the harder it is to demonstrate that 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 higher degree of difference between the averages (you can imagine this as less overlap between the ranges of values measured). There are no units associated with test statistics.

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 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. There are no units associated with test statistics.

8. How do I know what the results of my statistical test indicate? What does "statistical significance" mean? What is a *P* value? How do I know what a *P* value means?

Biologists interpret the results of their statistical tests by using an index called the "*P* value" to determine the "statistical significance" of their results. *P* values are commonly reported in biological literature, so it is important that you gain a sense of what they are and how to interpret them.

"*P* value" stands for "probability value;" *P* values range from 0 to 1. Biologists agree that a small *P* value indicates evidence for the existence of a difference between whatever is being compared (often different treatments in an experiment), and a large *P* value indicates a lack of evidence for a difference. By convention, a *P* value of less than 0.05 is considered an indication that the difference is "statistically significant." Any *P* value greater than 0.05 is considered an indication that there is no statistically significant difference between the treatments.

"Significant" in scientific writing is almost always used as a shortened form of "statistically significant:" it is closely associated with statistical analysis.

P values are used by biologists to interpret the results from statistical tests they may not be directly familiar with; they represent a sort of common language for talking about statistical results. 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. Note that statistical

significance does not indicate anything about the *importance* of a result.

Now that you have a general sense of what the *P* value represents, you may be wondering "if it is a "probability value," what is it the probability *of*?" This is an excellent question, and there are many common misconceptions about the answer. The statistical testing process starts off with the assumption that there is no difference between the two data sets being compared. (This is the "null hypothesis.") When you do a statistical test and get a *P* value, the *P* value indicates the probability that you might see these results under the assumption of "no difference."

Formally speaking, if your *P* value is below the level of statistical significance (in most cases, 0.05), this allows you to reject the null hypothesis. It also means your data support something called the "alternative hypothesis," which is typically just the idea that there *is* a difference between treatments. Note that proper interpretation of statistical results does not allow you to prove either hypothesis or to reject an alternative hypothesis. You can only reject the null hypothesis if it is extremely unlikely (less than a 5% chance) that you would arrive at that test statistic value if the null hypothesis were true. The smaller the *P* value, the stronger the evidence is that you can reject the null hypothesis and state that the alternative hypothesis is supported by your data. Be aware that a high *P* value does not give you evidence confirming that the two data sets are the same; it just indicates that you do not have the evidence to disprove the assumption of the null hypothesis.

9. How do I determine a *P* value?

A *P* value is determined based on the test statistic value and the sample size. Once you have calculated the statistic for your test (t-value, χ^2 statistic), you can use an internet resource like GraphPad's "P Value Calculator" (http://www.graphpad.com/quickcalcs/pvalue1.cfm), a free online resource. Excel will calculate *P* values for some tests as well. You can also find critical value tables 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.

10. What are "degrees of freedom?"

The "degrees of freedom" for a statistical test takes into account the sample size of your data. A higher sample size (n) is associated with more degrees of freedom. Typically, with more degrees of freedom, the test statistic value does not have to be as high to generate a statistically significant result. 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.

Preparing Tables and Figures for the Results Section

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. 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 that 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 that 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 that 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. A photo in a figure should be cropped and neatly annotated to make important patterns clear.

FAQ

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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 usually not a complete sentence, but a descriptive noun phrase with only the first word capitalized and a period at the end. Your title should include information about what organism was being studied (if relevant), what was being compared, and it can even (depending on the discipline) serve to summarize the main patterns or results. Your caption needs enough information that readers can understand and interpret the figure 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 should include the sample size(s) represented in the figure. 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. 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?).

Remember that figure captions go below the figure, while table captions go above the table.

Note: figure captions are sometimes called "figure legends" in the scientific community. Because of Excel's use of the term "legend" to mean a key to the colors or shading used for different data series, this can be confusing. We will use "figure caption" in this guide, but be aware that "figure legend" is often used synonymously.

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 that will be relevant to someone interpreting your table or figure. This might include 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. The degree to which methods information is included varies by discipline; pay attention to instructions from your lab instructor.

5. How do I number my tables and figures? What if I only have one figure: does it still need a number?

   Your figures and tables should be numbered in the order you refer to them in the text. Number your tables and figures separately: 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.) 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. 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 typically 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.

7. 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 use 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.

8. 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 in biological papers, though they may be common in other fields. If the bars on your bar graph represent averages, consider adding error bars that 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 "column chart" and "error bar" for help in constructing this sort of graph (note that in Excel, "bar charts" have horizontal bars and are not what you need). 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.

9. 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.

10. 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).

11. What is a semi-log plot?

    A semi-log plot is a special type of graph in which one axis has numerical values that 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 that 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.

12. How should I annotate a photo in a figure?

    First, make sure your photo is cropped so there is very little surrounding background. If you're pointing out a feature on an image (e.g. particular cells in a photo from a microscope), use arrows or arrowheads in white or black (depending on the background color). The arrows should not touch or cover the feature, and they should not cover up other important portions of the image. The caption should explain what the arrows are pointing at. If you are adding text to a figure to annotate it, use a clean, sans-serif font like Arial or Helvetica in white or black, and make sure any abbreviations are defined in the figure caption.

13. Are there general design considerations for figures and tables?

    Yes, absolutely. Make sure that your lines, symbols, axis labels, and all text are large or thick enough to be seen easily. If you use color, be thoughtful about your color choices; make the colors easy to distinguish and not distracting. If you use color in multiple figures to show different types of results for the same treatments, be consistent in assigning color for each treatment.

14. Where should I put my figures and tables?

    Your lab instructor may have specific instructions for you; typically, figures and tables are either placed within the Results section, at the end of the Results section, or at the end of the lab report. Make sure your figures are large enough so the font can be read easily.

Example Figures

See the examples after "The Results Section" below for descriptions of these figures.

From McKone et al. 2001:

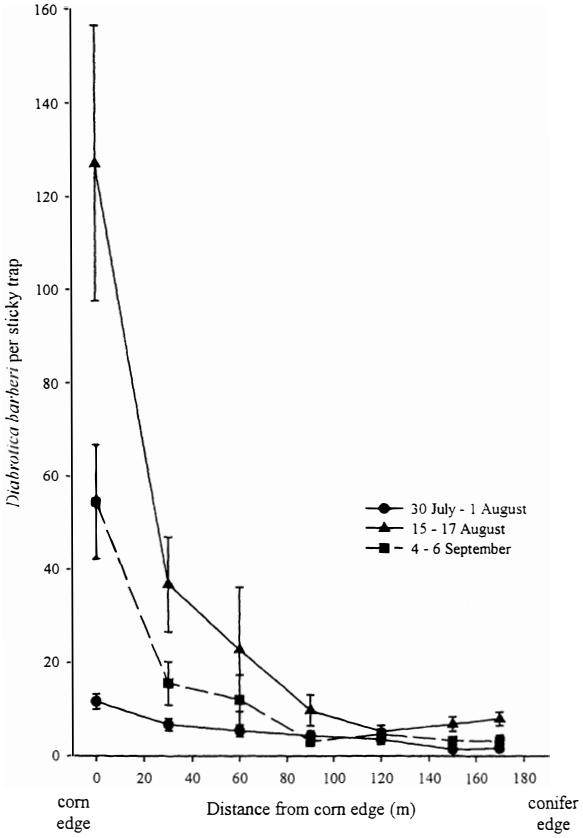

Figure 2. Number of* Diabrotica barberi *from 56 sticky traps exposed for 48 hours at three times during the season. Averages across eight transects (Fig. 1) are shown. Bars are ±1 SE.

From Sawai et al. 2003:

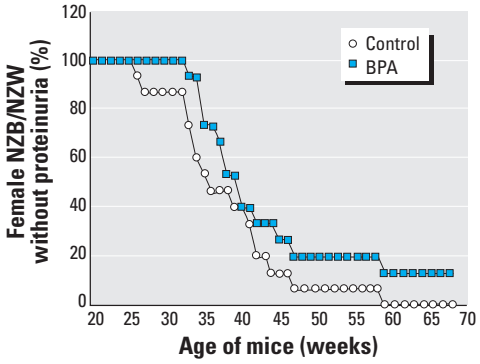

Figure 5. Development of proteinuria in 5- to 6-week-old female NZB/NZW mice fed PBS (n = 15) or BPA (n = 15) daily for 7 days.

From Kalis et al. 2014:

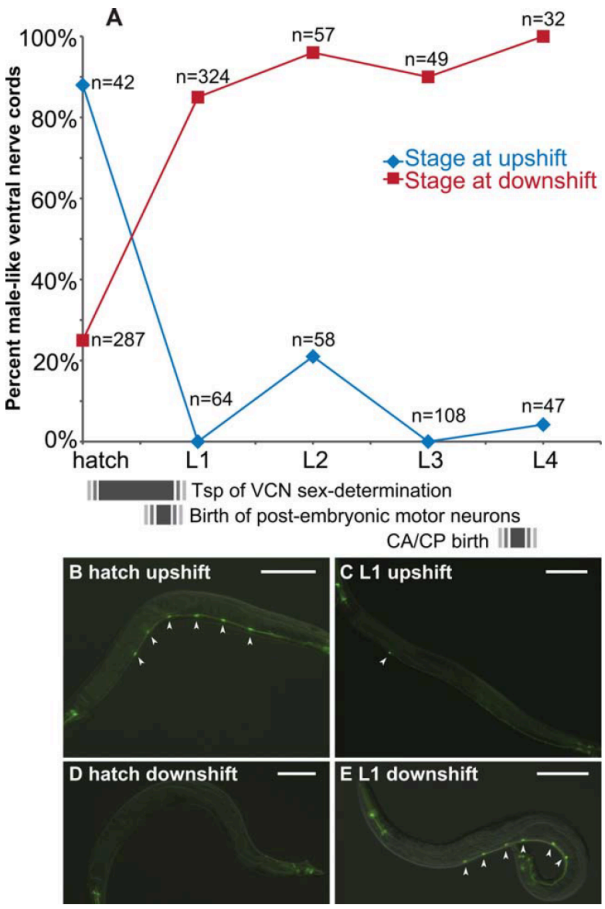

Fig. 2. The temperature sensitive period for VCN sex determination is during L1. **A:** Percentage of male-like ventral nerve cords (five or greater CPs) for upshifted (16°C → 25°C, blue) or downshifted (25°C → 16°C, red) populations at each larval stage. **B-E:** Expression of *tph-1::gfp(zdls13)* in *tra-2(ar221ts)* shifted animals. B: Male-like ventral nerve cords in animals upshifted at hatching, as represented by 6 CPs. C: Hermaphrodite-like ventral nerve cords in animals upshifted at L1, as represented by fewer than 5 CPs. D: Hermaphrodite-like ventral nerve cords in animals downshifted at hatching. E: Male-like ventral nerve cords in animals downshifted at L1. Arrowheads: CPs. Scale bars = 100 μm.

The Results Section

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. It should be clear how the results you are describing fit into the goals of the experiment. If this relationship is complicated, it may help to remind your reader why you are looking at a particular type of result; give your reader some context to strengthen the point you are making. 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 that 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 that 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 describe results not present in a table or graph?
6. How do I report results of comparisons for which I have not performed a statistical analysis?
7. How do I report results of statistical analyses?
8. Do I need to include my statistical calculations in my Results section?
9. How do I relate my results to the relevant figure(s)/table(s)?
10. 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 a few 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? 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 describe results not present in a table or graph?

   Unless specifically instructed otherwise, report all your results (even those without a figure or table, and even those which did not show statistically significant differences) in this section. Describe the patterns in the treatments you are comparing; don't forget to describe the nature of the results for any controls as well as experimental treatments. Use numerical descriptions whenever possible, and be precise in your language so the reader is convinced of any differences you are describing.

6. How do I report results of comparisons for which I have not performed a statistical analysis?

   Sometimes you will collect data that are not easily analyzed statistically, or that your lab instructor does not require you to analyze with statistics. You can still report the results of a comparison, but you need to make sure you avoid the term "significant," since that word signals that you have performed a statistical test. In describing your results, be as clear as possible about the nature of any differences. Avoid writing that two treatments were "very" different; there are many words like this that are judgement-laden and not useful in giving your reader a sense of the nature of the results. They are subject to different interpretations by different readers. Instead, describe the percent increase or decrease between two treatments (e.g., "survival increased 50% in the treatment compared to the control"), or state the fold-difference (e.g., "there was a five-fold increase"). Or describe them in terms of their similarity and/or variability; if the ranges of observed values are similar, you can note that (e.g. "the low and high temperature treatments averaged 5.6 and 6.0 spots per ladybug, respectively, and both groups had a range of 4 to 8 spots"). Be as precise as possible in describing the patterns in the data without listing all your data in the text: avoiding uninformative adjectives but also avoiding a long list of hard-to-follow numeric values will give your reader a better sense of your data.

7. 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, describe the nature of any significant difference (e.g., which treatment's average was greater), report whether the difference was statistically significant or not, and include the test statistic, degrees of freedom, and *P* value in parentheses. The parenthetical statistics support

the trends you're describing in the text of your Results section: they represent evidence supporting your claims in the text. 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 ($p=0.23$, $t=1.3$, 5 d.f.)." Here is a published 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). Your lab instructor may ask you to report specific values or a specific order for the values in parentheses; there are disciplinary differences.

P values are typically reported directly, with two significant figures, as in "$P=0.014$" or "$P=0.58$." When *P* values are less than 0.01, however, they are more commonly reported as "$P<0.01$," "$P<0.001$," 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).

If you determine a *P* value for a t-test is greater than 0.05, you would not describe the two groups you are comparing as different; you might state there is "no significant difference" between the two (note that "insignificant" does *not* have this particular statistical meaning in scientific writing, so you would say a difference is "not significant" rather than "insignificant"). While a *P* value above 0.05 means you cannot claim your results are different, you can describe trends in your data (but only if you think this is warranted) in your Results section and then in your Discussion call for more studies to see if the trends hold up with larger numbers of organisms.

8. 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 above. You do not need to include your calculations anywhere in your report.

9. 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 the results of our experiment" 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. See examples below.

10. 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 patterns in 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. Unless instructed otherwise, 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 Section Excerpts

Some of these excerpts refer to the figure examples in the previous section.

From Esch et al. 2013:
Across all 10 blocks, exotic cover ranged from 0 % in the least invaded block to 81 % in the most heavily invaded block. When considering the relationship between exotic cover and EEA and mineralization rates, increased exotic cover (as measured in April) was associated with increased EEA on CBH, LAP, NAG, and XYL in January (Fig. 2).

From Kalis et al. 2014:
To determine the temperature sensitive period for Pn.aap sex determination, we first performed a series of "upshift" experiments (Fig. 2). We shifted *tph-1::gfp (zdIs13)*; *tra-2(ar221ts)* XX worms from the hermaphrodite promoting temperature (16°C) to the

male-promoting temperature (25°C) at hatching and at each larval molt, then scored VCN expression of *tph-1::gfp* in young adults. Most worms grown at 16°C during embryogenesis, but shifted to 25°C at hatching express *tph-1::gfp* in five or six VCNs (Fig. 2B). However, those shifted after L1 rarely express *tph-1::gfp* in more than four VCNs (Fig. 2C).

From Lowe-Power et al. 2018:

Bacterial wilt disease alters tomato xylem sap to favour R. solanacearum *growth*

We collected xylem sap from healthy tomato plants and *R. solanacearum*-infected plants that had developed wilt symptoms within the previous 16 h (Fig. 1A). Unless otherwise noted, hereafter *R. solanacearum* refers to strain GMI1000. Even at this early stage of disease, sap exudation rate was 1.4-fold slower than in healthy plants, consistent with the model that bacterial wilt disease occludes xylem flow (Supporting Information Fig. S1). We filter-sterilized this ex vivo xylem sap from healthy and infected plants and measured growth of *R. solanacearum* in these media. Although at this disease stage sap nutrients are continuously depleted by the 10^9 actively growing *R. solanacearum* cells in each gram of tomato stem, the sap from two different *R. solanacearum*-infected tomato cultivars supported more *R. solanacearum* growth than sap from healthy plants (Fig. 1B). This was true under both aerobic and microaerobic conditions, and five of seven phylogenetically diverse *R. solanacearum* strains grew better in sap from plants infected by *R. solanacearum* strain GMI1000 (Supporting Information Fig. S2). We tested the possibility that healthy sap contained concentrated chemicals or defense proteins that inhibited *R. solanacearum* growth, but supplementing minimal media (MM) with sap from healthy plants improved *R. solanacearum* growth (Fig. 1C).

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 Reveillaud et al. 2018:

Microscopy and 16S rRNA gene and ITS analyses

As in other vent and seep vestimentiferans, numerous coccoid endosymbionts were observed using TEM in the trophosome tissue of the *Escarpia* and *Lamellibrachia* specimens. Although formalin fixation is not optimal for electron microscopy, the tissues were preserved well enough to see that the trophosome lobules contained numerous coccoid-shaped cells, ranging in diameter from 0.5 to 1.0 μm with cell envelopes resembling those of Gram-negative bacteria. An additional membrane was typically observed surrounding the symbionts, suggesting that as in other vestimentiferans symbioses, the bacteria are contained within membrane-bound vacuoles (Additional file 4A and B).

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. 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: refer to specific results to support your ideas. If you presented hypotheses and predictions in your Introduction, be sure to refer back to those: explain whether your predictions matched your results and whether your results support your hypotheses. As you explain the reasons for your results, you should present the most likely explanation first; if there are other possible explanations, these should be presented afterwards, with an explanation of why they are less likely.

In your Discussion, include 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)? How do your results compare to the results of previous studies? Put your work back into a broader context. Make sure you include a presentation of the limitations and assumptions of the study. For example, what are some of the assumptions you made in the design of the study or experiment that might need to be questioned? You will not be able to make grand conclusions based on this one set of results—don't try. Rarely, there may be a need to discuss errors that systematically affected your data in a misleading way, but the need to discuss your assumptions is much more common.

Your Discussion 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.

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.

The Discussion section is where the sophistication of your understanding really shows; it is also the section that 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 more narrow focus on your specific results and broadening to show how they fit in the larger context (note that this is the inverse of the typical Introduction section structure).

FAQ

1. What verb tense should I use in presenting my Discussion?
2. Should I use multiple paragraphs in my Discussion section?
3. How should I start my Discussion?
4. How long should my Discussion section be?
5. How do I know what conclusions I can draw from my results?
6. How do I explain what my results mean?
7. What do I do if my data seem to contradict previously published results?
8. 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?
9. How do I know if our results were affected by human error, and when should I discuss that?

———————

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 possibly 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 should I start my Discussion?

   Often, it is useful to start your Discussion by reminding your reader what your questions/goals

were, and to continue by addressing each of those, referring to specific results as they become relevant.

4. 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.

5. 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.

6. How do I explain what my results mean?

   Remember that you are trying to tell a story and convince your reader something about what your results mean. Be very clear about how particular results lead you to particular conclusions, and spell out the connections. Use your results as evidence to support your ideas, just as you use evidence in any writing to support your argument. You may also use results from other studies to support your explanation; describe and cite the relevant portions of other studies fully.

7. 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.

8. 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.

9. 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.)

Example Discussion Section Excerpts

From Beck et al. 2015:
[These are the initial two paragraphs in the Discussion section, which remind the reader of the patterns in their results, compare these patterns to those found in

previous studies, and the implications of their findings. You might also want to refer back to excerpts from the Introduction of this paper, above.]

Ecological determinants of serpentine community structure

Our findings suggest that both top-down and bottom-up controls influence the plant community composition of a serpentine grassland in a mediterranean climate. Climate, the most important bottom-up control in this study, was responsible for substantial interannual variation in plant community composition observed at Coyote Ridge between 2008 and 2013. Previous research has shown that precipitation strongly influences serpentine community structure (Hobbs and Mooney 1991, Hobbs et al. 2007). Both the timing and amount of precipitation were associated with plant community composition in our study. Total grass cover increased with winter precipitation, ranging from an average of 23% in the driest year to 45% in the wettest year, whereas native forb cover tended to decrease as grass cover increased.

Cattle grazing influenced both directional changes in plant community composition and the temporal community variability in this system. Within the interannual community patterns driven by climatic variability, we observed a divergence in community composition between grazed and ungrazed plots, beginning in the fourth year of experiment 1. Consistent with previous observational studies (Weiss 1999, Safford and Harrison 2001, Harrison et al. 2003), we found that grazed communities had reduced grass cover, greater native species richness, and greater native forb cover compared to ungrazed communities, indicating that grazing is an effective management strategy to maintain native richness on Coyote Ridge. Although grazing effects were less pronounced in experiment 2, there appeared to be a trend toward community divergence between grazed and ungrazed treatments.

[This is the final paragraph in the same Discussion section, which summarizes the main points of the paper and describes the implications of those results.]

Management implications

In this study, we show that grazing can be used to reduce exotic grass abundance, maintain native plant cover, mitigate the loss of native species, and promote community stability in serpentine grasslands at both ambient and moderately elevated levels of N deposition. Although grazing might not be an effective management strategy in all California grasslands (Kimball and Schiffman 2003), our results support the efficacy of grazing as a management tool in serpentine grasslands. Additionally, our findings have direct implications for the conservation of the federally threatened Bay checkerspot butterfly. In combination with its narrow range, limited dispersal ability, fragmented habitat, and annual life cycle, this butterfly's dependence on specific host plants leaves the species vulnerable to local extinction (Murphy and Weiss 1988, Harrison 1989, Weiss 1999, Zavaleta et al. 2009). Thus, increased plant community stability under grazing could maintain host plant abundance and nectar availability in this inherently variable ecosystem. Although the Bay checkerspot butterfly represents the best-studied insect species in serpentine grasslands, numerous other insects of conservation concern are present in the region (Connor et al. 2002) and might also benefit from the increased native plant abundance, diversity, and stability provided by grazing. Consequently, grazing may be necessary to maintain both diverse native plant communities and the insect communities endemic to California's serpentine grasslands (Weiss 1999, Connor et al. 2002, Safford et al. 2005). More generally, our study demonstrates how an understanding of top-down and bottom-up ecological controls can inform management strategies and mitigate the adverse ecological consequences of global change (Bobbink et al. 2010, Fenn et al. 2010).

From Indresano et al. 2003:
[The following is the final paragraph in this Discussion section, and summarizes future studies based on the results of this paper.]

Two issues will require further investigation: first, are these noise amplitudes physiologically relevant in the sacculus where hair bundles are restrained by their association with the otoconial membrane? Second, how is the performance of the organ "tuned" to provide the relevant noise amplitudes? Evolution might have shaped the organ's response by taking advantage of other intrinsic sources of noise (e.g., membrane voltage noise). Experiments using individual fibers might offer insights which are obscured by *en masse* recordings. Moreover, although the SNR of the nerve's response is a valid measure of a sensory system's response, it is possible that other measures of performance, such as the coherence between action potentials in individual fibers, or the rate of information transfer, might provide a better insight into the role of noise in the saccule's function

(Douglass et al. 1993; Collins et al. 1996; Levin and Miller 1996; Ward et al. 2002). The simple, yet rugged, preparation we have used here offers a convenient way to test some of these ideas.

From Linksvayer et al. 2002:
[The following paragraph is an example from the Discussion section of Linksvayer et al. (2002) regarding hitchhiking behavior in leaf-cutting ants. Note the reference to their figure, their own results, the results of other researchers, and the ideas of other researchers. The first phrase in the paragraph refers to a result from the paper which Linksvayer et al. discussed earlier in the section. This Discussion then goes on to cover other possible functions of hitchhiking.]

The difference in behavior of hitchhikers between day and night supports the possibility that parasite defense may not be the primary function of hitchhiking at night. During the day, hitchhikers were often in the head-up position (Fig. 3) that is characteristic of phorid defense (Eibl-Eibesfeldt & Eibl-Eibesfeldt 1967). This posture was significantly less common at night, which suggests that the hitchhikers did not defend against parasitoids as often at night. We agree with the suggestion of Bragança et al. (1998) that hitchhiking may have functions in addition to defense, especially at night.

From Nishizaki and Carrington 2014:
[These are the final two paragraphs in this Discussion section; they summarize the implications of the results in a broader context and suggest future directions for study.]

Our results underscore the need to consider multiple environmental factors when assessing physiological performance. The degree to which barnacle respiration is under mass transfer versus kinetic limitation depends on both water temperature and velocity. For example, studies conducted under low flows might only observe mass transfer limitation, whereas experiments run only at cool temperatures might only see kinetic limitation. As our results demonstrate, only a comprehensive survey of the temperature–flow landscape may reveal patterns of mass transfer and kinetic limitation.

The advantages of employing factorial experiments become even more pronounced when one considers the impact of rising ocean temperatures (Levitus et al., 2000). Our results suggest that we might expect different physiological responses to elevated temperatures on wave-sheltered versus wave-exposed shores. For instance, in areas with slow moving waters, barnacle physiology may become increasingly mass transfer limited as water temperatures rise. In contrast, at wave-exposed sites, faster water velocities may ameliorate the effects of rising temperatures on mass transfer limitation. Our results are consistent with the hypothesis that oxygen limitation may restrict the ecological distribution of marine organisms by lowering thermal tolerance (Pörtner and Knust, 2007). Moreover, our results demonstrate the limitation of inferences drawn from single-factor designs, and strongly advocate approaches that consider interactions among multiple factors.

From Nisi et al. 2015:
[This paragraph is in the middle of the Discussion section, and provides explanations for why their results did not support their hypotheses.]

Effects of distance from forest edge

Contrary to our hypotheses, there was not a strong effect of distance to the prairie-forest boundary on the rate of grazing. It is possible over a larger scale, herbivory levels would decrease as distance from the forest increases, but that our study area was not large enough to see these effects. The maximum distance of our transects from the forest edge (480 m) may be within the range where edge effects still occur. Alternatively, rabbits and deer may not be restricted to the forest. Particularly in the case of rabbits, prairie may provide them as much protection as forest, and one study (Bond *et al.*, 2002) found rabbits spend a substantial amount of time both in forest and grasslands. It is likely herbivory by rabbits and deer is common in restored prairies, as most prairie patches now occur in isolated fragments, rather than the large expanses of grassland that once characterized native tallgrass prairie. Additionally, some herbivores species may avoid areas near the forest edge. For example meadow vole herbivory has been shown to be greater in locations away from the prairie-forest edge (Nickel *et al.*, 2003). In the present study we were unable to distinguish herbivory among mammal species, which would have allowed us to determine how grazing patterns of each herbivore are uniquely affected by the proximity to forest. Nevertheless, proximity to the forest edge does not seem to have a significant effect on grazing of legume species in our study site.

From Reveillaud et al. 2018:
[The paragraph below is the final paragraph in this Discussion section.]

Together, the marked gene content and sequence dissimilarity (at the rRNA gene and whole genome level, with less than 75% ANI values) between hydrothermal and the seep endosymbionts studied herein suggest endosymbionts from the MCR belong to a novel tubeworm endosymbiont genus. We introduce the names *Candidatus* Vondammii proteani (i.e., named after the feature of sea-god Proteus, a figure of "flexibility, versatility and adaptability") and *Candidatus* Vondammii crypti to distinguish MAG1 and MAG2, respectively.

The Acknowledgements Section

Overview

The Acknowledgements section is very short, usually only a few 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

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 Kalis et al. 2014:
We thank Oliver Hobert, Paschalis Kratsios, and Roger Pocock for their generous sharing of strains and reagents and the following students for their contributions: Brittany Ganser, Ryan Kast, Sonya Krishnan, Joel Martin, Rachel Stephenson, Maria Sterrett, and current and former members of the Wolff lab. Some strains were provided by the CGC, which is funded by NIH Office of Research Infrastructure Programs (P40 OD010440). We also thank Shawn Galdeen and Sabrice Guerrier for their careful reading of this manuscript and David Zarkower and Mary Kroetz for helpful discussions. J.R.W. was funded by NSF Research at Undergraduate Institutions (RUI) and C.M.L. received an endowment from the Fletcher Jones Foundation.

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

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The Literature Cited Section

Overview

The final section in your paper is the Literature Cited section, where you list your references. (This is true for the journal *American Naturalist*, but in other journals, this section may be called "References;" be sure to check.) 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.

As you write this section, look over your in-text citations. Make sure you are not using direct quotes, and make sure you are paraphrasing without plagiarizing (see the Introduction FAQ for more information). Also, when you cite the results of another study, make sure it is presented clearly: include enough information that your reader is not required to read the cited paper to understand why you chose to reference it there.

The Literature Cited section should be written after citations are placed in the text; if you are using reference-managing software (e.g., EndNote), the Literature Cited can be created automatically as you insert references.

You should check with your lab instructor to find out what citation format to use. This guide uses *American Naturalist* format except in excerpts from previously published papers, which retain their original formatting.

FAQ

1. What is the basic *American Naturalist* format?
2. How do I cite an article in the text of my paper using *American Naturalist* format?
3. How do I cite the lab manual?
4. How do I cite information from handouts I received in lab or downloaded from the course management system (e.g., Moodle)?
5. How do I cite information from class, a professor, or another expert I talked to in person?
6. Why do some of the in-text citations of the *American Naturalist* paper contain the phrase "et al."?
7. How do I cite a paper with more than eight authors in *American Naturalist* format?
8. Some authors seem to cite themselves frequently; isn't that egotistical?

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

   If your lab instructor wants you to use this format, details are below. Your lab instructor may provide guidelines for a different journal instead; check if you aren't sure what style to use. 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 (and where they are *not*). 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. If there are more than seven authors, you may list the first seven as above, with the sixth and seventh authors looking like this: "G. H. SixAuthorLastName, I. J. SeventhAuthorLastName, et al." 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.

   For books, the format is similar:

   FirstAuthorLastName, A. B., and C. D. SecondAuthorLastName. YEAR. Title of book with first word capitalized and subsequent words lower case. Publisher, City Where Published, AbbreviatedStateName.

   If the book was published in New York, only the city name is given. For more reference types and specific examples, see a recently published paper from *American Naturalist*, available online.

2. How do I cite an article in the text of my paper using *American Naturalist* format?

Generally, do not quote the text of another paper directly; paraphrase the information and cite it (for more information, see the Introduction FAQ). Use a parenthetical, "Author Year" citation format. E.g. "(Day 1994)." The citations in this lab report guide take this format (although not the citations in the examples, since those are from a variety of journals with different citation styles). Parenthetical citations come before the period of a sentence, not after. For two authors, put both last names in your citation (e.g., "(Penrose and Katz 1998)"). If the paper you are citing has more than two authors, only use the first author's name, followed by "et al." (short for the Latin "et alia," which means "and others") (e.g., "(Esch et al. 2013)").

If you mention the name of the author(s) in the text of your sentence, you may put only the year in parentheses. For example: "Day (1994) wrote an amusing and highly readable description of writing scientific papers." The parenthetical year should be right after the author's name, not at the end of the sentence. If you are citing the same source in multiple sentences, be sure to cite completely in the first sentence. You should cite each subsequent sentence again unless it is absolutely clear the other sentences refer to the same source (for example, if the second sentence begins "In the same study…" it is unnecessary to cite a second time).

3. How do I cite the lab manual?

   Cite the lab manual parenthetically in the text like this: (Carleton Biology Department 2019). See the Literature Cited listing of this guide for an example of the proper format in that section (listed alphabetically by the "C" of Carleton). Use the current year as the year of publication, since the manual is revised each term.

4. How do I cite information from handouts I received in lab or downloaded from the course management system (e.g., Moodle)?

   Cite handouts as if they were part of the lab manual (see #3 above).

5. How do I cite information from class, a professor, or another expert I talked to in person?

   In the text of your report, cite information from a person parenthetically like this: (S. Deel, personal communication). Do not include an entry for the citation in your Literature Cited section.

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

   If a paper has more than two authors, only the first author is listed, followed by the words "et al." and then the year of publication (e.g., "(Esch et al. 2013)"). "Et al." is short for the Latin phrase "et alia," which means "and others."

7. How do I cite a paper with more than seven authors in *American Naturalist* format?

   In your Literature Cited section, list the first seven authors as you normally would, and end this list with "et al." before continuing on with the rest of the citation. Do not include the names of the eighth or subsequent authors in the Literature Cited section. Note that this varies by journal; some journals may list more authors.

8. 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 campus writing center 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. Other general formatting requirements may vary depending on sub-discipline and lab instructor. If you're unsure about formatting, check in with your lab instructor and ask for their preferences.

Check your paragraphs for cohesion: make sure you have incorporated elements like topic sentences and good transitions. Each section of the report should also have smooth transitions between paragraphs.

Avoid hyperbole and informal language; write concisely and directly.

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. You *can* describe in your Discussion how your results matched (or did not match) the predictions you presented in your Introduction.

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. Double-check the spelling of scientific names; often autocorrect is unhelpful in these cases (you might consider adding a commonly-used scientific name to your computer's dictionary). The word "species" is both singular and plural. The plural of "genus" is "genera."

Make sure all your measurements are reported in metric (SI) units; you should not use miles, inches, pounds, etc.

Do not begin a sentence with a numeral.

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

Make sure all the details of your figures are large enough to see in your final printed document. If you used color in your figures and are turning in a paper copy, make sure you print those pages on a color printer.

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 typically *only* used to refer to a difference which has been tested to be statistically different. Use the words "not significant" if you are referring to a lack of statistical significance: do not use "insignificant" for this purpose.

data: Traditionally, this word is only plural; the singular form of this word is "datum." However, the use of "data" as a singular is becoming increasingly common, and your lab instructor might not mind if you treat it as a singular noun.

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, if you are handing in a paper copy, your report 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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§ Carleton alum

Appendix: Common Challenges in Writing Biology Lab Reports

Sarah Deel, February 2011

	Problematic	Adequate	Exemplary
Issue In the Introduction section, students need to provide background relevant to the experimental question being asked. **Writing Strategy: Set the context** You are trying to tell a logical story with the lab report; make sure the context you are setting will help your readers understand your project and the scientific question you are addressing. Be selective in your choice of background information.	We used Asian lady beetles in our experiment. Asian lady beetles were introduced into North America for biological control of pests as early as 1916, with the first population becoming established in 1988 (Koch, 2003). The life cycle takes approximately 20 days from egg to adult, and adults can live 30-90 days (Koch, 2003).	We used Asian lady beetles, *Harmonia axyridis*, to study the effect of temperature on spot number. Development of coloration and its association with temperature has been studied in a variety of organisms, including chorus frogs (Harkey and Semlitsch, 1988) and monarch butterflies (Davis et al. 2005).	We used Asian lady beetles, *Harmonia axyridis*, to study the effect of temperature on spot number. Davis et al. (2005) found that monarch butterflies have darker wing coloration when reared at colder temperatures. We hypothesize that Asian lady beetles reared at colder temperatures will have more spots than those reared at warmer temperatures.
Issue: In the Materials and Methods section, students need to convert a lab manual protocol to a description of the general technique. **Writing Strategy: Consider your audience** If another scientist needed to repeat the experiment, knowing how we divided up our work among different groups of students is not useful. However, knowing the name and concentration of a particular solution used in an experiment would be crucial.	We placed 10 Asian lady beetles in each cage. So did the other seven lab groups in our lab. The cages were kept at 20°C (labeled with blue tape), 23°C (purple tape), and 26°C (red tape).	We reared eighty Asian lady beetles at each of three temperatures: 20°C, 23°C, and 26°C.	We reared eighty Asian lady beetles at each of three temperatures: 20°C, 23°C, and 26°C, representing a range the beetles might encounter in North American habitats.
Issue: In the Results section, students need to describe their results by summarizing important patterns: listing the numerical results of a test or saying simply "see figure 1" is uninformative. **Writing Strategy: Tell a story** Help your readers follow your arguments by summarizing important patterns; this will make it easier for them to remember these results when you discuss them.	We calculated the average number of spots in the offspring of the Asian lady beetles kept at each temperature (Fig. 1). - OR - At 20°C, the average number of spots was 7.1; at 23°C, 5.0; at 26°, 4.6.	We calculated the average number of spots in the offspring of the Asian lady beetles kept at each temperature (Fig. 1). We found the most spots occurred in the beetles raised at 20°C.	We found that the average number of spots in beetle offspring increased with decreasing temperature, from an average of 4.6 spots at 26°C to 7.1 spots at 20°C (Fig. 1).
Issue In the Discussion section, where students explain their results, they need to use their results as evidence to support their explanations. **Writing Strategy: Use evidence convincingly** Refer to specific values or patterns in your results which support the claims you are making. Clearly and explicitly lay out your description of the processes you believe are behind these results. Do not assume your reader will follow leaps in your argument.	Our results show that as temperatures decrease, the number of spots increases. Therefore, the decrease in temperature causes an increase in pigmentation.	The coldest temperature we tested, 20°C, yielded the highest number of average spots per Asian lady beetle, 7.1. This is consistent with the findings of Davis et al. (2005), who found more pigmentation in butterflies reared at lower temperatures.	We found an inverse relationship between temperature and number of spots, consistent with the findings of Davis et al. (2005), who measured more pigmentation in butterflies reared at lower temperatures. This relationship may allow for more absorption of heat from the sun, and therefore faster development in cold climates (Davis et al., 2005).