A. Strategy for writing your lab report

1. Read the directions

Seriously, don’t skip this step. If you read the directions right away, you are less likely to leave out mandatory parts of the lab report, you will be able to ask your instructor for clarification if necessary, and you can get set aside an amount of prep time appropriate to the scope of the project. Teaching assistants may also be able to provide guidance.

When reading the directions, be sure to make note of the due date(s). Depending on the assignment, there may be a single due date for a complete lab report or multiple due dates for different lab report components and/or drafts.

2. Find and read relevant literature

Your instructor has most likely provided you with information about the number and/or types of sources that should be cited in your lab report. For more information about finding the references used in a lab report, see Section B below.

3. Outline your lab report

Start by listing the required sections noted in the directions for the assignment. For the discussion section, also list the required topics (sources of error, future studies, etc.). Next, list the topics or even topic sentences for paragraphs in each section; in the results section be sure to note the locations for your figures and/or tables. If you haven’t created your figures and tables yet, sketch an outline of how they will be set up (axis labels for figures, column and row headings for tables).

4. Start writing

Different writing guides will suggest different sections to start with – our suggestion is that you start with whichever section, in your opinion, will be easiest. As you write, focus on the big picture for each section before focusing on detail; that is, set up a logical flow of paragraphs before worrying too much about the specific wording in the paragraphs. For more information about writing style, see Section C. For detailed descriptions of the standard components of a lab report, see Section D. A sample lab report is provided in Section E.

5. Review & revise!

Finish your lab report at least a few days early whenever possible. This will allow time for you to set it aside and review it with fresh eyes, and to hand it to friends and classmates so they can check for errors. Confirm that all of the required components listed in your directions are addressed in your lab report!
B. Finding references for a lab report

Primary vs. secondary references

In most, if not all, of your lab reports you will have to put your work in the context of previous research – that is, you will have to discuss your work as it relates to research described in primary references. A primary reference is a peer-reviewed, original description of a research study. Typically this is a journal article describing original research. Since a several types of article are published in research journals (e.g. review articles or commentaries in addition to original research), you cannot assume that all articles published in journals will qualify as primary references. Since scientists must be able to reproduce each other’s work, a primary reference will always include a description of the research methods. Sometimes it will be obvious from an abstract that an article contains a description of original research (the research methods may be summarized); at other times you will not realize until you look at the full text if you have a primary reference or a secondary reference.

A secondary reference can also be very valuable in preparing your lab report, even though it will not count as one of your required primary references. Many journals publish review articles, for example, that give you an overview of a specific topic. The authors of a review article might summarize the results of a hundred or more individual studies in a given research area, while evaluating the merits and drawbacks of the different studies and putting the findings into context. Review articles can be invaluable when trying to learn about an unfamiliar area of research. Other examples of secondary references include textbooks, commentaries and magazine articles. A lab report will typically require use of at least one secondary reference in the Introduction.

Since it can take some time to find, read and decide if you can use references, it is critical that these sources be identified well in advance of the due date for your lab report.

Search resources

A simple google search is unlikely to provide you with the references that you will need as you prepare your lab report. Your instructor may direct you to specific search resources or databases, but the two search resources most commonly used to find journal articles for biology courses are Google Scholar (http://scholar.google.com) and, for biomedical studies, PubMed (http://www.ncbi.nlm.nih.gov/pubmed). Effective use of these resources will require some judicious use of search terms. If you feel that your search terms are not yielding the types of articles that you are looking for, consult a research librarian, your instructor or your teaching assistant for assistance.

The biology libguide (http://mcla.libguides.com/biology) hosted by Freel Library contains a variety of search resources, including links to the online collections of journals housed in the Academic Search Premier and JSTOR databases. If you do your literature search through one of the links on the libguide (e.g. the Google Scholar tab at http://mcla.libguides.com/biology/articles), the articles freely available through the MCLA databases should appear as free full text in your search.
Full-text journal articles

If you have a lot of relevant articles at your disposal, you can limit the articles retrieved in a PubMed search to those with free full text. In Google Scholar, free articles are usually indicated with links on the right-hand side of the screen. In most cases, however, the articles most relevant to your work will not be freely available. You have several options for obtaining these articles.

1) Use interlibrary loan. An option, though not the quickest option. See a reference librarian for assistance with this.

2) Email the corresponding author. This is a good option, though you might need to do some detective work to find the author’s email address. Sometimes it is listed with the abstract, otherwise you can do a search for the name of the corresponding author (if noted) or the last author (the boss) combined with the institution (university or company at which they did the work), and you should be able to find an up-to-date email address. In your email, politely and professionally ask for a PDF copy of the article. Be sure to note the title, year and journal for the article. In most cases you will receive a reply within a few days.

3) If you don’t have a few days and the corresponding author is not responding, see if Williams College (http://library.williams.edu/) has the article. If so, get someone to drive you there – there are public access computers at Sawyer Library (the main library) and Schow Library (the science library) at which you can access the college’s journal articles. You will not be able to save the PDF, unfortunately, but you can purchase a print card and print the article(s) there.

4) Purchase the article. You will not even consider this option, because it would mean you procrastinated to the point that none of the other options are possible. You would never do that, right??

Websites of suitable authority

Depending on the instructor and the assignment, you may or may not be permitted to use websites as references. (Note that journal articles that are available in print but can be accessed online are considered to be journal articles, not websites, for reference and citation purposes). If you do intend to use a website as a reference, take care to evaluate it to determine if it is a suitable source. Is the website published by an institution or individual that would be widely accepted as a reliable and knowledgeable authority? If you have any doubt, check with your instructor. When obtaining information from websites, be sure to note the information that you will need for the reference list in your lab report (author, title, revision date or accession date, website; see an APA style guide, e.g. https://www.library.cornell.edu/research/citation/apa).
Other sources
You can typically cite your textbook and/or lab manual as books in your lab report; other books may also be used for background information. These will not qualify as primary references. Articles from newspapers and magazines are not suitable resources for a lab report.

C. Writing style
A complete review of suitable writing style will not be provided here. Resources that can help you to improve your writing style can be found under the “Writing Resources” tab of the Biology LibGuide (http://mcla.libguides.com/biology). The following are some of the issues and errors specifically encountered with lab reports in biology:

Watch your language!
Scientific writing is concise, precise and professional. Words should be chosen with care to avoid vagueness (“we added 100 ml of water” rather than “we added some water”) and unnecessary detail (“the subjects ran up and down a flight of stairs for 5 minutes” rather than “the subjects, who were wearing workout clothes, were timed by an observer with a black electronic stopwatch as they ran up and down the stairs between the first and second floors in the science building from 11:00 to 11:05 am, for a total of 5 minutes”).

Contractions are typically avoided in scientific writing (“the fruit flies did not wake up from anesthesia” rather than “the fruit flies didn’t wake up from anesthesia”).

To quote or to summarize?
Quotes are not used in lab reports, and minor rewording to “paraphrase” is also inappropriate for scientific writing. For the most part you will be summarizing the key ideas in an article. If you paste a summary sentence from an abstract or a textbook then try to reword it, you will undoubtedly run into problems – in addition, the key point that the article’s authors were trying to make may not be the same point that you are trying to make. It is best even when making notes to summarize key points (citing the source) rather than copying sections of text. For more information, see the sections “Quoting, Paraphrasing and Summarizing” and “Taking Notes” in the “Citing and Documenting Sources” tab of the Biology Libguide (http://mcla.libguides.com/biology).

Present vs. past tense
Verb tense will vary in a lab report. The present tense is used for descriptions of information that is widely accepted as true (or at least can be backed up by a published, peer-reviewed reference). Information that could be found in a textbook will always be written in the present tense (“yeasts are single-celled organisms”). The findings of published research studies are usually written in the present tense (“fruit flies are attracted to rotting bananas”), though a scientist’s actions in a published study are
written in the past tense, for example: “Smith et al. (1978) observed that fruit flies were [or are, your choice] attracted to rotting bananas.”

The description of your own study, since it has not been published and accepted in the field, will be written in the past tense (“carbon dioxide accumulation was higher for plants kept in the dark,” “the bacteria were Gram-positive”).

**Passive vs. active voice**

There is no strong consensus in the field of Biology with regards to use of the active voice (“I did”) or the passive voice (“it was done”). Find out from your instructor if he or she will allow the active voice. If the active voice is acceptable, you may use “I” or “we” as the subject in sentences that describe your actions, though that should still be kept to a minimum. If the instructor prefers exclusive use of the passive voice, there should be no use of “I” or “we” in the document.

**Frequently mis-used words**

**Significant**

Significant has a very specific meaning in biology. If you say that there were significantly more brine shrimp on the light side of the tank, or that the plants kept in the dark were significantly smaller, that means you did a statistical analysis of your data and found a difference with a \( p \) value <0.05. Do not use the word “significant” in any other way in your lab report.

**Data**

Data is a plural (singular: datum). “Data were collected after 12, 24 and 48 hours.” “The data from this experiment support our hypothesis.”

**Affect vs. effect**

Spell-check and grammar-check will not help you here – you must think consider your word choice every time you use “affect” or “effect” in your lab report. *Affect* is a verb (A is for Action); “the loud noises affected the behavior of the fish.” *Effect* is a noun; “different effects were observed with different chemicals.” Effect may, in rare cases, be used as a verb (= to bring about), but unless you are quite comfortable with this use, stick to the previous rules!

**Support vs. prove**

Biologists must be open to the possibility that ideas about how living things function will change based on new data. We therefore hate the word “prove,” since “prove” suggests that an answer is final. A single experiment doesn’t prove anything (particularly not a single, small-scale experiment conducted in a 3-hour lab block). Your data don’t prove or disprove your hypothesis – they can only support or not support your hypothesis.
Writing numbers and units

Unless followed by a scientific unit, numbers under twenty should be spelled out in the text (fifteen leeches, 4°C, nine plants, 5 mL). If a number starts a sentence, it must always be written out, even if it is followed by a unit (sometimes it is easier to rearrange your sentence than to write out your number!)

The abbreviations for scientific units should be used; these need not (and should not) be spelled out at any point in the text. Use the degree symbol (°) rather than the word degree when describing temperatures – to find this, and to find the “±” for standard deviation and the “µ” for µL, click on the “Insert” tab in Word. Select “Symbol,” and then scroll through the options till you find the symbol that you need. Double-click on it or select “insert” from the bottom.

Abbreviations

Some abbreviations are sufficiently standard that you do not need to define them in your lab report (DNA, RNA, mRNA). Other abbreviations must be defined at first use. (“The primary antibodies were dissolved in phosphate-buffered saline (PBS) at a ratio of 1:100. The secondary antibodies were dissolved in PBS at a ratio of 1:1000”). Minimize the use of abbreviations in your lab report – you are typically not restricted to a maximum number of words in a lab report, so make it as easy as possible for your reader to understand your text.

Chemical names (NaCl, H+°) do not need to be defined, nor do abbreviations for scientific units (mm, µL, min).

Specialized terminology

If you use specialized terms in your lab report that would not be familiar to most of your classmates, define or explain them in the text. (“The reduction in herbivory could be due to high levels of phenols, which are defensive chemicals made by plants.”)

Scientific names

Remember that genus and species names must always be written in italics (Hirudo medicinalis). After the first use of the genus name, it can be abbreviated (H. medicinalis). The species component of the name must start with a lower-case letter – note that auto-correct might try to make it a capital letter. When specifically referring to a kingdom, phylum, class, order or family for an organism, the name must be capitalized (“the medicinal leech Hirudo medicinalis belongs to phylum Annelida”), but if you are not using the official name, do not capitalize (“leeches are annelid worms”).

D. Components of a lab report

The following are the standard components used to describe a research study – you will find them in both lab reports and journal articles, though formats may vary somewhat.
1. Title
The title will be a short, informative description of the experimental purpose, research question or research findings.

Sample titles:
- Rate of lactose digestion at different temperatures.
- Dinoflagellate responses to increases in temperature.
- Fruit flies are more attracted to apple cider than to apple juice.

2. Author
For a lab report you, the writer, are the author. For group submissions there may be multiple authors. Your lab partners should also be acknowledged, if they contributed to the research. You can list lab partner(s) below or next to the author name(s).

For some assignments (e.g. drafts submitted for peer review), anonymous submissions will be required. Do not list the author or lab partners on these drafts!

Sample author list:
- Author: Anne Goodwin
- Lab Partners: Justin Golub, Sarah Herrick, Jerry Smosky

3. Abstract
The abstract is a concise summary of the research study. This section should always be written last, so that you have the key points from each of the other sections to draw from. Include a sentence (at most, two sentences) addressing each of the following:

a) Introduction. Provide context for your study, but don’t cite references.
b) Research question or the purpose of the experiment. Be very clear about why the study was done.
c) Experimental design. Provide an overview of how the study was done without going into great detail.
d) Results. Summarize the main findings.
e) Conclusions. State the take-home message from your study, based on the findings.

Sample abstracts:
The salt content in water that plants take up can potentially affect plants growth and development in different ways. In this experiment, our group watered *Brassica rapa* plants with a 2% salt water solution from the time of planting to see what its effects would be on their growth and development. We planted eight seeds to be treated with the salt water and eight seeds that would be the control in normal tap water. There were five dependent variables that were recorded after four weeks of growth: stem height, total number of leaves, number of seed pods, number of flowers, and average leaf length per plant. Our results showed that the salt solution affected the
total number of leaves that grew on each plant. These results showed that the plants were not as adversely affected by the salt solution as we had thought they would be.

In this lab, *Drosophila melanogaster* was used as a model to study development because of the wide range of research that has already been performed on this organism. In this experiment dissected and whole individuals were observed to examine physical characteristics including sex, larval body forms, imaginal discs, eggs, and polytene chromosomes. During the experiment we anesthetized flies and examined their body shapes and we dissected individuals to remove the imaginal discs and the polytene chromosomes within the salivary glands. Additionally, we observed larval forms and normal and dechorionated eggs. Based on the results of the lab we were able to recognize and understand the importance of the various life stages of *Drosophila melanogaster* as well as understanding the purpose of the structures involved in development.

4. Introduction

The purpose of the introduction is to explain to the reader why it was important that you did your research study. The introduction will contain the following information:

a) **Background about the research topic.** This information will be organized from general (information about your system or test organism) to specific (importance of your particular research question), and all information provided should directly serve to emphasize the relevance of your study. General information will typically be obtained from secondary references such as textbooks and review articles. Primary references may or may not be used to introduce your research question, depending on the primary references at your disposal and on the instructor’s directions. Background information from secondary sources will be written in the present tense, past or present tense may be used in descriptions of research studies from primary references, as noted above.

The background portion of the introduction is typically two paragraphs in length. Citations must be provided for information that is not common knowledge; see the references section below for instructions for citing references.

b) **Research question or purpose of experiment.** This will typically be a single sentence, phrased as a statement or question.

*Sample experimental purposes or research questions:*

The purpose of this laboratory activity was to determine the rate of lactose digestion by lactase.

This led to the following research question: are fruit flies attracted to sugar?

We therefore wondered if temperature would change the behavior of leeches.
c) **Hypothesis** (if appropriate). If the experiment addressed a research question, include the hypothesis at the end of the introduction. The hypothesis should be written as a statement expressing a prediction.

*Sample hypotheses:*

I hypothesized that leeches would be attracted to warm water.

The hypothesis was that fruit flies would be attracted to a solution containing sugar.

We predicted that heart rate would increase with exercise.

If fruit flies are attracted to sweet things, then fruit flies will be caught in greater numbers by a solution containing sugar.

*Sample introduction:*

Dinoflagellates are single-celled organisms that live in freshwater and saltwater environments. Some species live in symbiosis in corals, including the species *Symbiodinium adriaticum*, which is what our experiment is using. The experiment we are performing falls under the question of “How do changing ocean conditions affect dinoflagellates?” The oceans of the world are undergoing changes such as salt content and the increasing depths of the ocean from the melting polar ice caps. How will these factors affect marine life, including symbiotic dinoflagellates in corals? Costa *et al* studied the effects of seasonal dynamics in the coastal reefs off Picãozinho in Northeast Brazil and their effects on cell density and photosynthetic pigment contents of the zooxanthellae hosted by the dinoflagellate species *Montastrea cavernosa* (Costa *et al*, 2004). They found that cell numbers were greater in the rainy season, photosynthetic pigments were greater in the dry season, and that both parameters drastically dropped in amount during heavy rains. They speculated that this pattern is because of the rain cycles and how they affected the water clarity and the seasonal physiological condition of the cells (Costa *et al*, 2004).

Perhaps, when the water is clouded and murky, the dinoflagellates could not absorb enough light of their preferred spectrum to carry out photosynthesis, and therefore could not survive. Our group decided to test a similar aspect of water quality. We wanted to see if the color of the water, rather than the turbidity of the water, had any effect on dinoflagellate survival. *Symbiodinium adriaticum* have brown photosynthetic pigments, so we decided to color the water in the experimental flasks brown using food dye. This way, the water stayed clear, but it was a different color for light to pass through. In a natural setting, a change in water color could be due to an algae bloom or if a chemical got into the water that caused it to change color. An example of change in water color but not clarity in a contained ecosystem would be if you were treating a household aquarium with medicine containing Malachite Green to treat a fish parasite infection. It causes the water to turn a bright blue color, but doesn’t affect the clarity of the tank water. Our group hypothesized that water colored brown by food dye will have a negative effect on the growth of the *S. adriaticum* populations in the three test flasks.
5. Methods

The methods section is a critical component of a lab report or a published research study, as scientists must be able to reproduce each other’s work. Your methods section should be written in such a way that a classmate could reproduce your experiment based on the information provided. The methods section must be written in the past tense, using paragraphs rather than a list format. A separate list of materials is not included in biology lab reports; key materials are simply mentioned as they are used in the experimental setup and measurement procedures. Be sure to include the following information in the methods section:

a) **Experimental setup.** Note which research organisms were used, if appropriate, and how those research organisms were obtained. Describe your experimental procedure, citing the lab manual if appropriate. Include all information needed to reproduce the setup and interpret the results, but do not provide excessive detail—that is, information not needed for reproducing the experiment or interpreting the results (for example, it is not necessary to include the fact that cups were labeled 1-6, that volumes were measured using a graduated cylinder or that temperature was measured at 1:56 pm – someone could reproduce your experiment without any of this knowledge).

b) **Human studies (if appropriate):** If you used humans as the subjects in your experiment, explain how the subjects were recruited and note the rules used to exclude subjects from your study. Provide a subject characteristics table containing the ages, sexes and any other relevant information about your subjects. Do not include the subject names here or anywhere else in your lab report. Do note that the experimental protocol received IRB approval.

c) **Data collection.** Note how observations were made, how measurements were done and any other information relevant to how the data were collected.

d) **Statistical analysis.** Note which statistical tests were used, and name the statistical software used to conduct the statistical tests.

**Sample methods:**

We observed and collected data on populations of shaving brush algae in Little Lameshur Bay on the island of Saint John in the United States Virgin Islands. We counted algae over a one-quarter square meter area at multiple sites. We were able to locate three suitable seagrass beds each containing Manatee Grass and Turtle Grass. Within each seagrass bed, one group member positioned our quadrat at one-half meter intervals. At each of the seagrass beds, we placed the quadrat into each seagrass bed at the decided interval five times, giving us a total count of 15 observations. For each time we placed the quadrat down, we performed a visual count of the number of algae individuals, and then we photographed the site for later examination in order to prevent any miscounts. An analysis of variance was carried out to determine the difference between group means.
6. Results

The results section will provide a written summary of your findings that can be understood independently from – and is complementary to – your figures and tables. Summarize your findings, citing each figure and table, and provide appropriate statistical descriptions (for example: means, standard deviations, p values, t statistics) as requested by your instructor. Note trends and observations, and be sure to use the word “significant” only in the statistical sense. Do not provide any interpretation of your results here (no opinions, no notes about the importance of the findings).

When describing differences between groups or trends in data, take care that your descriptions match your statistical analysis. For example, you cannot suggest that two groups are different if the p value for the comparison is > 0.05. (“Heart rates were not significantly different between the two groups. Heart rate was 80 ± 4 bpm for group A and 84 ± 3 bpm for group B, p=0.34.”)

The results section is usually quite short in a lab report. The results shown in each figure or table will typically be described in a single sentence (for a simple graph) up to, at most, a paragraph (for a complicated graph or table, or for observations). Again, do not forget to cite each figure and table as you describe the findings!

Sample results:

The SDS-PAGE procedure provided information to determine Rf values for the standard samples. The values vs. log molecular weight were plotted on an xy scatter plot to generate the protein standard curve (Figure 1). The slope of the line was used to calculate the molecular weights of the samples. Porcine pancreas was calculated to be 151.93 kDa, Bacillus licheniformis 141.82 kDa, and Aspergillus oryzae 141.82 kDa (Table 1).

Protein standard markers were used on the Western Blotting nitrocellulose paper to calibrate the molecular weight markers (Figure 2). The results from Western Blotting were the human salivary α-amylase band was present on the nitrocellulose paper however porcine pancreas, Bacillus licheniformis, and Aspergillus oryzae were non-reactive and did not exhibit colored bands (Figure 3).

7. Figures and tables

Your data will be summarized in the text, but table and figures are essential in allowing the reader to interpret the results of your experiment or laboratory exercise. Care must be taken to design tables and figures to highlight data trends and key findings for the reader. Data tables and figures are considered part of the results section, and each table and figure must be cited in the results text; for example, “Heart rate increased after exercise, from 80 ± 4 bpm to 124 ± 9 bpm (p<0.05, Figure 1).”

Figures or tables?

Tables are particularly useful if you are providing descriptive observations, showing information for each of your research subjects, or if a variety of measurements were taken in your experiment. Graphs are most frequently used for comparisons and to
show trends. Graphs, photographs and diagrams are all considered figures. Tables and figures that show subject characteristics or aspects of the experimental procedure are typically placed in the methods section; tables and figures that show experimental data are placed in the results section. Do not place tables and figures at the end of the document unless directed to do so by your instructor.

Sample decisions about how to present data

| Heart rate and blood pressure (systolic and diastolic) are measured before and after exercise for ten subjects; you would like to draw attention to information for each individual subject in addition to showing average results for the group | Table |
| You would like to show that the average heart rate after exercise is significantly higher than the average heart rate before exercise for your subjects | Figure (bar graph) |
| You would like to show that the average heart rate decreases over time once exercise stops | Figure (line graph) |
| You would like to show a correlation between heart rate and systolic blood pressure after five minutes of exercise | Figure (scatter plot with trendline) |
| You would like to emphasize the distributions of heart rates for your subjects before and after exercise | Figure (box plots) |

Table setup

Each table (and figure) will need a number and a descriptive title. The title of a table is positioned above the table, and any explanatory information is provided below the table. Since people typically read from left to right before up to down, it is best to place your subjects as rows and your data measures as columns. Each row should have a title, and each column should have a heading. If you are using human subjects, do not include their names in data tables (or anywhere else in the lab report).

Sample table:

Table 1: Molecular Weight and Rf Values for Standards and Samples.

<table>
<thead>
<tr>
<th>Source</th>
<th>Molecular Weight</th>
<th>Rf Value</th>
<th>Log of MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>50</td>
<td>0.538</td>
<td>1.69897</td>
</tr>
<tr>
<td>Standard</td>
<td>75</td>
<td>0.410</td>
<td>1.87506</td>
</tr>
<tr>
<td>Standard</td>
<td>100</td>
<td>0.384</td>
<td>2.00000</td>
</tr>
<tr>
<td>Standard</td>
<td>150</td>
<td>0.333</td>
<td>2.17609</td>
</tr>
<tr>
<td>Standard</td>
<td>250</td>
<td>0.282</td>
<td>2.39794</td>
</tr>
<tr>
<td>Bacillus licheniformis</td>
<td>141.82</td>
<td>0.333</td>
<td>-</td>
</tr>
<tr>
<td>Aspergillus oryzae</td>
<td>141.82</td>
<td>0.333</td>
<td>-</td>
</tr>
<tr>
<td>Porcine pancreas</td>
<td>151.93</td>
<td>0.317</td>
<td>-</td>
</tr>
</tbody>
</table>
**Graph setup**

Graphs are powerful tools for communicating important aspects of your data. The type and overall appearance of your graph must be carefully considered.

With the exception of pie charts, each graph will have an x axis and a y axis. The x axis will typically show the independent variable (the group, category, individual, or variable that you control – for example, the concentration of enzyme in a given tube). The y axis will typically show the dependent variable (the variable that you measure).

In many cases means (or averages) will be graphed rather than individual data points. This will allow trends or comparisons to be better visualized than with a depiction of all data points. When averages are shown, error bars (“whiskers” above and/or below a bar or point) are typically used to show standard deviation or another measure of variability. Standard deviations should not be graphed as stand-alone bars; see your instructor if you are unsure of how to graph variability for your experiment.

Each graph is considered a figure, and each figure will have a number (Figure 1, Figure 2). The figure number and figure title will be provided below the graph, as the beginning of the figure caption (called a “legend” in scientific writing). Additional information needed to interpret the graph should be provided in the legend. The number of subjects/replicates (“n”), markers of statistical significance (“*, p<0.05) and the measure of variability (“error bars show standard deviation”) are often included in the figure caption/legend. If abbreviations are used in the figure labels, these should be defined in the figure legend.

**Types of graph**

Many different types of graphs that can be used as figures in lab reports; these include bar graphs, line graphs, scatter plots, box plots and pie charts.

**Bar graphs** are used when you are comparing groups (men vs. women, hot vs. cold, before vs. after, 22°C vs. 37°C). Error bars will be used to show standard deviation or other measures of variability. The categories/group names are shown on the x axis and the measured value is graphed on the y axis. The bars should have informative labels on the x axis (for example, “warm” and “cold” rather than “A” and “B”). Unless otherwise directed by your instructor, make sure the y axis starts at 0. For more-complicated groups of data (e.g. with more than one series), the two measures you want to compare should be shown next to each other, and an informative key should be used to differentiate the series (see the two-series graphs in the samples below).

**Sample bar graphs:**
Figure 1. Percent of *Strongylocentrotus* eggs fertilized per condition. ASW, artificial seawater; CaFSW, calcium-free seawater; NaFSW, sodium-free seawater. Error bars show standard deviation.

Figure 2. Actual heart rate vs. perceived heart rate before, during and after moderate exercise on a rowing machine. The perceived heart rate was calculated by multiplying the rating of perceived exertion (RPE) by 10. N=3. Error bars show standard deviation.

**Line graphs** are used when you want to show average (or individual) measurements made over a continuous variable such as time, temperature or concentration. The continuous independent variable (time/temperature/concentration) is graphed on the x axis and the measured value is graphed on the y axis. If two lines are shown, comparisons can be indicated by marking statistically significant differences between the groups at specific times/temperatures/concentrations. Unless otherwise directed by your instructor, make sure the y axis starts at 0. When averages are graphed, error bars can be added to the points on the line to show standard deviation or another measure of variability.

Sample line graph:
Figure 3. Behavioral response to predator cues after hatching. Fry from embryos exposed to goldfish (predator; closed circles) or not exposed to goldfish (control; open circles) were challenged by exposing to goldfish starting at 5-7 days after hatching (Initial fry challenge). Fry challenges were repeated 1, 2, 3, 4, 6, 8, and 12 weeks after the initial challenge. The time to resume normal foraging behavior (recovery time; Log$_{10}$ seconds) was recorded for each fry challenge. Error bars represent 95% confidence intervals.

Scatter plots are used to show trends and correlations; individual data points are graphed rather than averages. As in a line graph, the x axis must show a continuous variable – either an independent variable or, for correlations, one of two measured variables. A trendline ("best-fit" line) can be added to the graph to show trends in the data.

Sample scatter plot with trendline:

Figure 4. Protein standard curve for alpha-amylase, as determined by SDS-PAGE, with Rf reflecting the distance the band traveled relative to the log of the molecular weight.
**Box plots** are used to emphasize the distribution of data within a group. The box contains the middle 50% of the data points, with a line showing the median, and “whiskers” extending from the box indicate the minimum and maximum.

*Sample box plot:*

![Box plot](image)

**Figure 5.** Scores on the first and second exams for a biology course.

**Pie graphs** are used to show composition of your research populations or observations.

*Sample pie graph:*

![Pie chart](image)

**Figure 6.** Taxa composition of sample taken from Site B (n=102). Ephm. = Ephemeroptera.

**Photographs or diagrams**

Photographs or diagrams may be useful in describing results or in describing experimental methods (for the latter case, the figure should be cited in the methods section).
8. Discussion

The discussion section allows analysis of the implications of your findings. Take care to frame the discussion around your actual results, not the results you hoped for or predicted based on your hypothesis. Unless otherwise directed, you must cite at least one primary reference in the discussion section; a description of the appropriate format for in-text citations is provided in the “References” section below.

There are several standard topics that are typically addressed in a discussion.

a) Relate your findings to your hypothesis or to the purpose of the experiment. If your research was hypothesis-driven, note if the results supported or did not support your hypothesis. Do not say that your hypothesis was proven/disproven, or that your hypothesis was true/false – a single experiment can only support or not support a hypothesis. If your experiment was organized around an objective rather than a hypothesis, note whether the objective was met, based on your results.

b) Compare your results to those of published findings, if appropriate. You must typically use at least one primary reference in this part of the discussion. You will note if your findings agreed with those described in the published study, and you will describe how your study was similar to and different from the published study in terms of methods. This comparison will typically require one paragraph per primary reference. You will use the past tense in describing the methods and results of both studies. Don’t forget to cite the published study.

c) Speculate about unexpected results and provide sources of error. In the introduction, you explained why you expected certain results. The discussion is the appropriate location for speculation about unexpected results. You might have noted aspects of the procedure or conditions during the experiment that might have influenced the results. Furthermore, statistically significant trends are rarely shown when sample sizes are small and variability high (that is, most experiments carried out in biology labs). This speculation will typically account for a paragraph in your discussion.

Whether your results were expected or unexpected, experimental procedures can typically be improved in a variety of ways. Provide possible sources of error related to your experimental design or the way in which you carried out the procedures. (If you already addressed some of these in detail in speculating about unexpected results, you can mention these briefly here, without going into great detail again.) Follow up by explaining how the experimental design could be improved to address some of these sources of error. This section will typically account for one or two paragraphs in the discussion.

d) Describe a future study, if appropriate. A future study is not simply a new study that addresses procedural flaws described in the sources of error section. A future study must logically take the experiment in a new direction – for example, by addressing a new or revised hypothesis or research objective, or by using a new procedure to address the same hypothesis or research objective. Provide some description of the new experimental strategy. This section will typically account for one paragraph in your discussion.
e) **Conclusion.** End your discussion with a sentence or two summarizing the take-home message(s) of your lab report. Feel free to be very obvious about this, for example by starting the sentence with “In conclusion”.

**Sample discussion:**

Data analysis has shown that there is no significant statistical difference in population numbers of *Penicillus capitatus* between different species of seagrass beds. Wilson and Ramsook (2007) performed a study that examined population densities of epiphytal foraminiflora on seagrasses and algae, such as *Penicillus capitatus*. During the course of their study, they noted that populations of *Penicillus capitatus* grew in abundance in both species of seagrass beds, just as was the case in our experiment.

During our data collection, there were several possible sources of error that could have impacted our results. For one, we only took 15 population counts for each type of seagrass bed over the course of two days. Our data would be more valuable if we were to take more population counts overall. Second, only one of the bays we planned to use before arriving in the Caribbean was usable for data collection, significantly limiting the area we were able to work in. Therefore, we were able to get population counts for *Penicillus capitatus*, but those population counts may only be relevant in the one bay we worked in. In the future, it will be beneficial to alter experimental design so that more population counts can be recorded and multiple locations can be used for experimentation.

A potential future study could be to examine populations of *Penicillus capitatus* on several different types of substrates, including different species of seagrass beds. This study should be performed ideally over several months, with several hundred population counts in order to gain more viable data. In conclusion, the experimental data revealed an insignificant difference in population means for *Penicillus capitatus* among different species of seagrass, but further experimentation should be performed in order to gain the most feasible results.

9. **References**

Include all references cited in the text – and only those cited in the text. Consult the directions for your lab report to confirm the required numbers and types of references. Unless otherwise directed, use the modified APA format described here for in-text citations, and use standard APA format for the reference list. Online APA formatting guides and links to reference management programs such as EasyBib and RefME are provided in the “Citing Resources” tab of the Biology Libguide (http://mcla.libguides.com/biology/citing).

**In-text citations**

A modified version of the APA in-text citation style will be used for in-text citations in biology lab reports. Do format your in-text citations as (name, year), as in APA style. Type the author’s last name (no first name, no initials), then a comma, then the year of the publication. For two authors, provide both names, then the year. For three or more
authors write “et al.” after the first author’s last name, without listing all of the subsequent authors’ names. et al. = et alia = and others; take care to put a period after the “al”, as this is an abbreviation. In APA style, up to five authors are listed when a reference is first cited; the “et al.” even at first use is more typical for publications in biology. If the author names are provided as part of the sentence, put the year only in parentheses at the end of the sentence.

Sample in-text citations:

Smosky and Billetz (1995) observed that fruit flies were more attracted to overripe bananas than to underripe bananas; similar results were reported by Goodwin et al. (2015).

Leeches can sense a variety of stimuli, including chemicals and heat (Herrick, 2014). Leech feeding behavior is influenced by these and other stimuli (Golub et al., 2015).

General rules for the reference list

Put the references in alphabetical order by the last name of the first author; do not change the order of the authors listed in the publication. Use initials rather than full first and middle names. Provide the author name(s), year of publication and title of the resource, followed by information specific to the resource type, as noted below. If a reference requires more than one line in the text, indent all lines after the first.

Instructions and extensive lists of examples for references in APA style can be found at https://www.library.cornell.edu/research/citation/apa and https://owl.english.purdue.edu/owl/resource/560/06/, among other websites. Examples for some common types of references are provided below.

Journal articles

Author. (Date). Title of article. Journal, volume, pages. [if accessed online, also include one of the following:] doi: [insert doi number] OR retrieved from: [insert url].

Smosky, J. (1980). A strain of fruit flies that is resistant to anesthesia. Journal of Interesting Research, 5, 76-87. doi: 123456789


Books

Author or Editor. (Date). Title of book. City of publisher: Publisher. Pages [if only a portion of the book is being cited].
E. Sample lab report

Relationship between an overnight fast and blood pressure

Steven Miller
Lab Partner: Ashley “Erin” Kelley

Abstract

One in four Americans is predicted to develop metabolic syndrome, which includes high blood pressure. Modern medicine views hypertension as related to diet and lifestyle. The reason for this experiment was to see if an overnight fast had a decremental effect on blood pressure. It is known that postprandial changes in mean arterial pressure and heart rate are significant, but the effects of a short term fast are not known. A group of young, healthy students from a college class fasted overnight and their mean arterial pressure was monitored for changes. These results were compared to those of similar students who did not fast overnight. No significant difference in mean arterial pressure was observed between fasting and nonfasting students. The hypothesis that lower blood pressure would be seen in the experimental (fasting) group was not supported by the data.

Introduction

A full third of Americans have hypertension and there is a greater than 90% risk of developing this condition within one’s lifetime (Bakris 2007). When one’s diet is based on fruits and vegetables, low-fat foods, and reduced saturated fats, blood pressure goes down dramatically (Appell et al., 1997). It is noted that these foods have a high water content and that subjects in that study drank increased amounts of water. Going a step further, many people generally believe that a water fast will dramatically lower blood pressure.
It was decided to test the idea that a very short term water fast would lower blood pressure. If it did, then perhaps a regimen of fasting every other day or every three days might be a suitable method of controlling blood pressure. Dr. Mark Mattson, a popular proponent of calorie restriction as a way to health and longevity, noted in a piece of research that intermittent fasting (in rats) can reduce the normal growth related increase of end systolic and end diastolic volumes (Wan et al., 2010) that determine stroke volume. On the opposite side of the fence, another study showed that cardiac output, heart rate, stroke volume, and systolic and diastolic pressures all increase after a meal (Varady et al., 2009). In fact, one is urged by the study authors to never to have a postprandial cardiac evaluation because it will be abnormal! The hypothesis of the current study is that overnight fasting from solid food through breakfast time (12 hours) will significantly lower blood pressure from normal levels in a healthy person.

Materials and Methods

In this experiment eight student volunteers were solicited from the anatomy and physiology class. Effort was made to select people as randomly as possible, however it is noted that most class members were young females with normal blood pressure. Many of them had been athletically conditioned. Two chosen subjects were males with widely differing ages, neither of whom had high blood pressure. Subjects were divided into two groups so that there were four reasonable replicates in each group. Directions for a fasting event were given, allowing no food or snacking after the evening meal until class the following morning, roughly 12 hours. Students were to allowed to drink as they normally would, or if thirsty, but no extra beverages were allowed to compensate for lack of food. Two groups were formed. The experimental group agreed to an overnight fast and the control group ate and drank as they normally would.

Blood pressure was measured with an aneroid sphygmomanometer. A stethoscope was available. Blood pressure data were recorded for each person before and after the fasting event. Data were entered into a spreadsheet as systolic pressure, diastolic pressure, and pulse rate. The Mean Arterial Pressure (MAP) was calculated as \[\text{MAP} = \frac{\text{diastolic pressure}}{0} + \frac{1}{3}(\text{systolic pressure} - \text{diastolic pressure})\]. To compare the difference in MAP between fasting and nonfasting groups, the final MAP was calculated as a per cent of the original. Numbers greater than 100% were therefore increases, and those less than 100% were decreases, from base line MAP.

Differences were analyzed using the t-test in Microsoft Excel. Using the paired t-test, it was assessed whether the mean change of MAP was statistically different within the fasting group or nonfasting group. Using the unpaired t-test, it was assessed whether the mean change of MAP was statistically different between the fasting or nonfasting group. In all cases the level of significance was \(\alpha = 0.05\).

Results

For fasting students, there was no significant difference in MAP before and after the fast (78.24 ±11.01 vs. 81.13 ±8.36, \(P = 0.66\), Figure 1). For nonfasting students, there was also no significant difference in MAP on the first or second measurement days (82.47 ±15.63 vs 76.47 ±11.47, \(P = 0.27\), Figure 2). Comparing the blood pressures for fasting and nonfasting students, the final MAP as a percentage of the
original MAP for fasting students was not significantly different from that of nonfasting students (105.07% vs. 93.64%, Figure 3).

Figure 1. Mean arterial pressure (MAP) for fasting students before and after fasting. N=4. Error bars indicate standard deviation. P=0.66.

Figure 2. Mean arterial pressure (MAP) for nonfasting students before and after the designated fast day. N=4. Error bars indicate standard deviation. P=0.27.

Figure 3. Final mean arterial pressure (MAP) as a % of the original MAP for fasting and nonfasting students. N=4. Error bars indicate standard deviation. P=0.26.
Discussion

In this study all subjects maintained their normal blood pressure with or without a fast. Maintaining the same blood pressure was, of course, totally expected from nonfasting students. It was not expected in fasting students. Clearly, the data do not support the hypothesis that a 12 hour fast in normally healthy subjects will significantly lower blood pressure and heart rate.

In our study focusing on normotensive students, a single fast did not reduce blood pressure. A significant decrease in systolic pressure from 124±5 to 116 ±3 (P < 0.05) was observed after an alternate day fasting protocol over 10 weeks (Varady et al., 2009), a fasting protocol that was much longer than ours. The study described by Varady et al. (2009) involved more subjects, and the subjects were obese.

Errors might have been made in measuring blood pressure. A more rigorous process for this study would have been to be sure the arm was level with the heart, to have subjects seated for several minutes before taking measurements, to use the stethoscope rather than just looking at the needle on the aneroid sphygmomanometer, and to have the same person doing all measurements. In addition, it would make for a sounder protocol to take multiple measurements and average them together for the data analysis, or to use a much larger and broader sample. Another limitation of this study was the homogeneity and limited number of the subjects and, perhaps more specifically, that they all had normal pressure that did not need to be lowered. Therefore, even had the results shown a drop in blood pressure and heart rate from fasting, one would be remiss in suggesting a fast for lowering blood pressure for hypertensive individuals.

That fasting students maintained mean arterial pressure may be the result from the power of homeostasis and the inability of a short-term fast to modify the strength of long-term hormonal (ANP vs aldosterone) controls on blood pressure. It would be interesting to try a longer fast of perhaps 24 hours. Alternatively, a study might be done with a focus on repeated fasts. It would be interesting to experiment with the hypothesis that an 18 hour fast, two days per week, for three months will significantly lower high blood pressure and, perhaps, in certain age groups, the risk of a cardiovascular event.

In conclusion, a decrease in blood pressure was not seen for students without hypertension who did an overnight fast.

References


### F. Acknowledgements

This handbook was written by Anne Goodwin; contact her by email with suggestions for improvement. Many thanks to the students and faculty of the Biology Department at MCLA for helpful feedback regarding the contents of the handbook. Samples of student work were used, in modified or unmodified form, with permission from Sara Bouchard, Alice Croteau, Annie Gagnon, Michael Lamoureaux, Amanda LeBarron, Steve Miller and Elizabeth Pitroff.

### G. Bibliography

Many resources were read during the preparation stage of writing this handbook. These works were helpful in framing priorities for some sections but were not directly used in preparing the text; as such, this is a bibliography rather than the reference list (=cited references) required for your lab reports. If you are interested in purchasing a reference book, the texts marked with “*” are recommended.


