Part 1: Writing In the Sciences

1.1 Purpose of a Scientific Paper

The purpose of a scientific paper is to share new discoveries with other scientists. Also called journal articles or peer-reviewed papers, scientific papers are the primary way scientists communicate.

Because they are reporting new results from original research, authors of scientific papers must:

- state the scientific question they hoped to answer,
- show that their methods have the potential to answer the question, and
- provide a logical and compelling interpretation of their results within the context of existing knowledge.

If these conditions are not met, other scientists will reject the paper's conclusions. It is therefore crucial that scientific papers be well-written and convincing.

1.2 Purpose of a Lab Report

Unlike scientific papers, lab reports generally describe experiments that have been done many times before. Because the expected results are already well-established, the purpose of a lab report is somewhat different:

- to allow students to demonstrate mastery of procedures conducted in the lab,

- to allow students to demonstrate their understanding of the scientific principles the lab was designed to explore, and
- to teach students how to write scientific papers on original research later in their academic careers.

The audiences for scientific papers and lab reports are also different. While papers are written by scientists for other scientists, lab reports are written by students for their instructors. Use the report to prove that you understand the purpose of the experiment, and more importantly, that you can use scientific knowledge and principles to explain the data you collected in the lab.

1.3 Planning Your Report

Successful lab reports are clear, well-organized, and concise. Prior thought and planning make these traits much easier to achieve.

First, make sure you have:

- taken detailed notes during your experiment, so you need not rely on memory,
- gathered necessary reference materials, such as lab manuals, textbooks, journal articles… and,
- completed any analysis or calculations required for your assignment.

Before beginning to write, ask yourself:

- What was the goal of the experiment? What scientific principle was it meant to

demonstrate? What question was it meant to answer?
- What data should be included, and what data are unimportant?
- How should the data be presented? Can it be summarized in words alone, or will tables and/or figures be more effective?
- What do the results mean? What is the explanation for what you observed? If multiple explanations are possible, are some more likely than others?

1.4 Writing Style

Scientific writing requires grammatical and stylistic approaches that differ from those preferred in other academic disciplines. Lab reports, literature reviews, and theses will be most successful when they comply with these conventions.

1.4.1 Tone

Scientific writing is straightforward, specific, and concise. Avoid unnecessary jargon, choosing simple, precise words instead. Readers will draw conclusions based on the strength of the data, not the beauty of the writing.

Clarity is more important than poetry. Observations should be reported using concrete nouns, verbs, adverbs, and adjectives rather than figures of speech: for example, the colour of a mixture should be described as “bright green,” not “the shade of new spring leaves.” A writing style that is direct and uncluttered reduces the chance that readers will misunderstand or become confused.

1.4.2 Voice

In **active voice**, the subject of the sentence is active: the subject performs the action expressed by the *verb*.

> *Examples of active voice:*
>
> My lab partner and I *diluted* each sample with 100 mL of water.
>
> We *diluted* the samples, causing them to change from bright green to pale green.

Active voice emphasizes the people who are doing the experiment, rather than the procedures or results themselves. Science, however, is universal—anyone should be able to do a particular experiment and get the same results.

In scientific writing, therefore, the emphasis should be on facts and data, not the researcher. This requires use of passive voice.

In **passive voice**, the subject is inactive, receiving the action expressed by the *verb*. In other words, the subject is acted upon by an unseen party.

> **NOTE:** Passive voice is not the same as past tense, which denotes *when* an action occurred.

> *Examples of passive voice:*
>
> Samples were *diluted* with 100 mL of water.

Diluting samples caused them to change from bright green to pale green.

In addition to changing the emphasis of the sentence, passive voice removes unnecessary detail, making the sentence more concise.

> **NOTE:** Some professors and professional journals accept limited use of active voice in scientific writing. Always check with your professor before using active voice.

1.4.3 Using the Literature

It is extremely rare to include a direct quotation in a scientific paper: in most cases, the facts are more important than the specific wording previous authors used to express them. In general, quotes are only appropriate if the original wording is so powerful and precise it is impossible to improve upon.

Information from research sources should therefore be paraphrased, and must be cited in text.

> **TIP:** Paraphrasing involves stating the facts in your own words. Both vocabulary and sentence structure must be different from the original. To avoid accidentally plagiarizing, try covering your source before writing.

Examples:

A new method for developing fingerprints on spent cartridge casings was discovered in 2009 (Bond and Heidel).

Bond and Heidel (2009) discovered a new method for developing fingerprints on spent cartridges.

A new method for developing fingerprints on cartridge casings takes advantage of corrosion reactions between skin oils and brass (Bond and Heidel 2009).

Use the correct citation style for your discipline:

- Biology – Canadian Science Editors (CSE)
- Chemistry – American Chemical Society
- Environmental Sciences – APA
- Physics – Physical Review Letters

NOTE: Your professor may request a citation style not listed here. Whatever style you use, be sure to apply it consistently.

All sources that appear in the text of the paper must also appear in the reference list. See section 2.10 for further instructions and resources.

1.5 Scientific Vocabulary

Many words commonly used in conversational or academic English have different meanings in the context of science writing. It is important to use these words correctly to avoid confusing or misleading the reader. Some of these problematic words, and their scientific usages, are given below.

Word or Phrase	**Commonly Found in**	**Definition and Guidelines**
Hypothesis	Introduction Discussion	A proposed explanation for an observed phenomenon. A hypothesis can be experimentally tested.
Theory	Introduction Discussion	A hypothesis that has been thoroughly tested and is supported by so much experimental evidence it is generally accepted as true.
Model	Introduction Discussion	A physical, mathematical or conceptual framework that shares key characteristics with a natural object or phenomenon. Used to explore, explain, or predict the real thing.
Accurate	Results	Refers to how closely an experimental measurement reflects the true value.
Precise	Results	Indicates a high degree of similarity between repeated measurements.
Significant	Results	Commonly used as a synonym for "important." In scientific writing, shorthand for "statistically significant," meaning a high probability that the observed relationship between two variables is due to more than chance. Typically accompanied by the results of a t-test or

		other measure of statistical certainty.
Correlation	Results	The degree of similarity in the way two variables change. A statistical calculation expressed as an R value. Two variables can be correlated in the absence of a causal relationship.
Cause	Results	Indicates that one variable changes *as a result* of change in the other variable.
The data support/suggest	Discussion	Implies that the evidence is consistent with the explanation presented, but other possibilities could not be ruled out.
The data indicate	Discussion	Implies a high level of certainty that the proposed explanation is most likely to be the correct one.
Proof	Discussion	Absolute certainty that a conclusion is correct. Used in mathematics and logic, but not generally applicable in science writing.

Part 2: Sections of a Lab Report

2.1 Organizing Your Report

TIP:
It is generally easiest to begin by writing the Materials & Methods section, followed by Results, Discussion, Introduction, and Abstract.

Lab reports are typically broken into sections following a core format known as AIMRAD (Abstract, Introduction, Materials & Methods, Results, and Discussion). The AIMRAD format is often modified, however, to suit the needs of a particular scientific discipline. By understanding the purpose of each section in the core format, you can easily adapt your reports to meet the requirements for any science course.

In the following pages, AIMRAD sections are explored in depth and examples provided. **If you are writing for Biology or Environmental Sciences, use the core format presented in the main text unless your professor indicates otherwise. Notes in the sidebars highlight typical modifications used in other sciences.** ***<u>Your professor may require additional modifications not described here: when in doubt, always follow your professor's instructions.</u>***

2.2 TITLE

Titles should be clear, descriptive, and capture the major purpose or result of the experiment. Include the keywords you would use when searching for information on this subject in a library database.

Examples of bad titles:

> Subject of experiment unclear.

Lab Report 2

Temperature and Fruit Flies

> Relationship between variables unclear.

Examples of good titles:

Effects of Temperature on Generation Time in Fruit Flies (*Drosophila melanogaster*)

> Scientific/ Latin name given in brackets.

Using Light to Improve Cardiac Function After a Heart Attack[1]

> Describes purpose of the experiment.

Reconstructed Storm Tracks Reveal Three Centuries of Changing Moisture Delivery to North America[2]

> Describes major result.

---

[1] Inspired by Cohen, J. E., Goldstone, A. B., Paulsen, M. J., Shudo, Y., Steele, A. N., Edwards, B.B. et al. (2017) An innovative biologic system for photon-powered myocardium in the ischemic heart. *Science Advances 3*(6), e1603078.

[2] Wise, E. K., & Dannenberg, M. P. (2017) Reconstructed storm tracks reveal three centuries of changing moisture delivery to North America. *Science Advances 3*(6), e1602263.

2.3 ABSTRACT

Abstracts appear in many types of academic papers, including lab reports. Abstracts allow:

- papers to be indexed in library systems and online databases, and
- other researchers to decide whether papers contain information relevant to their own studies, without reading the entire work.

Abstracts summarize an entire paper in a few hundred words; as a result, they are generally considered the hardest task in academic writing. Writing the abstract last, when it is clear what details in the lab report are really important, makes this process easier. This approach also ensures that the abstract accurately reflects the content of the finished paper.

> **NOTE:** Professors of first and second year courses may not require abstracts. If your assignment includes one, ask whether to use the descriptive or informative style.

Abstracts:

- appear at the beginning of a lab report, before the introduction,
- are concise, packing large amounts of information into a small number of words,
- are clear, making them accessible to readers from other scientific disciplines,
- typically present information in the same order as the body of the paper,
- use the same verb tenses as the body of the paper (e.g., past tense for methods, present tense for generally accepted facts),
- do not reference tables, figures, or sections of the paper, and
- do not include references to cited literature.

2.3.1 Descriptive Abstracts

NOTE: Descriptive abstracts are most often used in the humanities. In science, they are typically reserved for literature reviews, rather than lab reports.

A descriptive abstract introduces the content of a report without going into specific detail. Similar to the "teaser" paragraphs on the backs of novels, these abstracts provide a general description without "giving away the ending." Descriptive abstracts:

- resemble an outline, rather than a full summary,
- include information on the purpose and scope of the report,
- do *not* include results, conclusions, or recommendations, and
- are usually less than 100 words.

Example 1:

Using DNA from insects trapped in amber, billionaire John Hammond has brought dinosaurs back to life. During a preview of his new Jurassic Park, however, security systems are disrupted and the living exhibits escape. Paleontologist Alan Grant, lost in the park with Hammond's grandkids, must find a way to outrun the hungry dinos—before the reptiles drive the humans to extinction.

Example 2:

Concrete was first used as a building material in the days of the Roman Empire. This report describes advances in concrete technology and outlines the fundamental role of concrete in the construction of several modern mega-projects.

2.3.2 Informative Abstracts

NOTE: Informative abstracts are most often used for lab reports or original research papers.

Informative abstracts provide a complete summary of the contents of the paper, including essential results and conclusions. Rather than teasing the reader, they reveal everything needed to determine whether reading the entire report will be worthwhile. Informative abstracts:

- include 1-2 sentences for each section of the report, highlighting major ideas, results, and conclusions,
- place the work in the context of the field,
- provide specific details, such as numerical data, uncertainty estimates, or statistical significance, and
- are approximately 10% of the report's length, to a maximum of around 250 words.

Example 1:

Using DNA from insects trapped in amber, billionaire John Hammond has brought dinosaurs back to life. During a preview of his new Jurassic Park, however, security systems are disrupted and the living exhibits escape. Paleontologist Alan Grant and Hammond's grandkids are trapped in the park, but manage to evade the hungry predators and make it back to the command centre, where they help the staff and other visitors restore the Park's systems. After several near misses, the surviving humans escape the park, having learned that extinction really should be permanent.

Informative abstracts give away the ending (by presenting key conclusions).

Example 2:

Concrete has a long history as a building material, but modern engineering mega-projects demand unprecedented strength and durability. To meet the 100-year lifespan required for the Confederation Bridge project, flat-sided gravel was replaced with custom-cast six-sided stones. This increased surface area, strengthening bonds between cement and aggregate. Addition of fly ash further increased strength, while silica fume decreased permeability, reducing the destructive effects of corrosive seawater. The blend showed an exceptional resistance to freeze-thaw cycles during laboratory testing, suggesting the Bridge will endure for decades without the need for significant repairs.

> Compare the level of detail in this abstract to that of the descriptive version on page 13.

Example for Physics

The experimental value of the gravitational constant, G, was verified with a Kater's reversible pendulum. Kater's experiment was important because it was the first accurate measurement of G, and, therefore, its verification is also important. <u>A reversible pendulum's equal period point was measured, resulting in an initial G value of $8 \pm 1 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, which is not consistent with the actual value of G ($6.674\ 08 \times 10^{-11}$ m^3 kg^{-1} s^{-2}).</u> Using fine increments, a more accurate value of $6.6 \pm 0.2 \times 10^{-11}$ m^3 kg^{-1} s^{-2} was experimentally determined. The uncertainty value is mostly attributed to inconsistency in placing the pendulum exactly 90 degrees on the pivot, and with imperfections in the knife-

> Abstracts for Physics and Physical Chemistry must include the consistency check, which compares the experimental result to the accepted value. Note that the check statement (underlined) must include both the measurement and its significance or uncertainty – do not describe your results as "close."

edge of the pivot that cause friction. Despite these limitations, the refined version of the experiment confirmed the value of G, which is important to know for accurate interpretations of interstellar data, and for maintaining satellites in orbits.

2.4 Introduction

The Introduction is the first section of the main body of a lab report. It provides information needed to understand the purpose and importance of the experiment.

PHYS: The Introduction may be called "Theory," or Theory may be used as a sub-heading within the Introduction. All equations must be described in words: define terms and explain the purpose of the calculation. State any assumptions.

2.4.1 Providing Context and Essential Background

Every scientific experiment builds upon existing knowledge and understanding. The Introduction summarizes this knowledge for the reader. Introductions begin with general background, gradually becoming more specific. Rather than providing a broad overview of the entire field, introductions focus on key concepts or discoveries that are directly relevant to the present experiment. The goal is to show how the current experiment fits into a broader context of historical or current scientific thought.

NOTE: This part of the Introduction answers the question, "What did we already know about this topic?"

2.4.2 Identifying the Purpose of the Experiment

Introductions explain why the current experiment is necessary, by identifying a gap in existing knowledge the experiment will attempt to fill, or a question the experiment is designed to answer. It is important to clearly define how the experiment will contribute to scientific understanding of the topic or phenomenon under investigation. For example, will it expand our knowledge or have practical applications?

NOTE: This part of the introduction answers the questions, "What is the reason for undertaking the experiment?" and "Why is this research important?"

In many first and second year labs, the goal of the experiment is to demonstrate or confirm established phenomena.

Example:

In this excerpt, notice how the first paragraph provides a general orientation to the research topic. The second paragraph is much more specific, guiding the reader toward the focus of the current experiment. Note as well that the purpose of the research ("improve landing performance") is clearly identified.

Landing is the final phase in aerial routines (take off phase, flight phase, and landing). Landing is important for success in gymnastics and is therefore of interest to researchers and coaches who want to improve landing performances.

Landing success depends on the physical fitness (preparation) and motor control of the gymnast. Physical preparation refers to the gymnast's ability to cope with the load to which they are exposed during the landing. Motor control refers to the control the gymnast has over the skill they perform. Both of these factors enable successful and safe landings.[3]

2.4.3 Outlining the Experimental Design and Stating the Hypothesis(es)

An introduction explains the theoretical or practical approach to the research question, without providing too much detail (details will be given in the Materials & Methods section). If a specific

[3]Adapted from Marinsek, M. (2010). Basic landing characteristics and their application in artistic gymnastics. *Science of Gymnastics, 2*(2), 59-67.

hypothesis is being tested, it should be mentioned here.

NOTE: This part of the introduction should answer the question, "How and why will the experiment produce answers?"

Example:

Monozygotic (identical) twins have been extensively studied in humans (e.g. Hrubeck and Robinette, 1984) but are rarely documented in other mammals (Gleeson et al., 1994). In fact, no published record confirming monozygotic twinning in any wild carnivore species could be found. This paper presents what may be the first evidence of such twinning in a wild caniform carnivore, the grey wolf (*Canis lupus*).[4]

This paragraph is the entire Introduction of a short scientific paper. Notice that the authors identify why the research is interesting and important. Also note that in this descriptive study, no hypothesis is necessary.

2.4.4 Writing Tips for Introductions

- Write the Introduction when the Results and Discussion are already complete. Only then will you know what information is needed to properly introduce the experiment.
- Because Introductions summarize existing knowledge, they incorporate information from previously published sources. Reference all non-original material using an appropriate citation style for your field (see section 2.10 for details).
- Use a mixture of past tense (for describing previous research) and present tense (for generally accepted facts). The current experiment can be described in either

[4]Adapted from Carmichael L. E., Nagy, J. A., & Strobeck, C. (2008). Monozygotic twin wolves with divergent life histories. *Arctic 61*(30), 329-331.

present tense (e.g. "This experiment determines…") or future tense (e.g. "This experiment will determine…").

Example:

This is the final paragraph of an Introduction. Note that the authors paraphrased and cited information from several previous studies. Also note that past tense is used to describe former experiments and present to describe this report.

Explains how results of the experiment could be used – i.e., why the research is important.

Experimental method (approach to the problem).

Alternative explanations (hypotheses) for the phenomenon under investigation.

In 1999, *C. l. arctos* was considered for protected status by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) but was not listed due to insufficient data (Van Zyll de Jong & Carbyn, 1999). An improved understanding of the nature and characteristics of wolves on the Arctic Islands may facilitate assignment of an appropriate conservation priority, permitting management decisions suited to wolf populations inhabiting the changing Arctic environment. **This paper explores island wolves' genetic health and potential for persistence via analysis of nuclear microsatellites, estimating genetic variation and inbreeding within island wolf populations, and assessing level of inter-island, and island-mainland, gene flow.** *The goal was to determine whether recovery of island wolf populations has been entirely due to the impact of increased prey density on local survivors, or is prompted by over-ice recolonization from other wolf populations (Manning and MacPherson, 1958; Usher, 1965).* Although microsatellites are not well suited to subspecies-level investigations (Paetkau et al 1997), they are used here to construct a preliminary molecular hypothesis regarding the evolutionary origin of *C. l. arctos*.[5]

---

[5]Adapted from Carmichael L. E., Krizan, J., Nagy, J. A., Dumond, M., Johnson, D., Veitch, A, & Strobeck, C. (2008). Northwest

The Materials & Methods section has two goals:

- to describe the experiment clearly enough that someone else could replicate it, and
- to show that the experimental method is appropriate for the research problem or question, implying trustworthy results.

CHEM:
Title this section "Experimental Procedure."

All critical details of the experimental design should be included, such as: controls, treatments, variables measured, number of replicates, which measurements were actually taken, and how the data was analyzed. Include the names of any software programs used, and details of any calculations or statistical tests that were performed.

PHYS:
Materials & Methods is sometimes called "Apparatus & Procedure."

Keep careful notes on your procedures while conducting the experiment, and particularly, any deviations from the instructions in your lab manual. Write the Materials & Methods section of the report as soon as the experiment is complete, while the details are fresh in your mind.

PHYS:
A labeled photo or diagram of equipment used must always be included in this section.

2.5.1 Writing an Effective Methods Section

Lab manuals are generally written in "cookbook" format, with a list of materials and a numbered set of instructions. This style, while helpful in the lab, should never be used when writing your report.

Instead, Materials & Methods sections are written using full sentences and paragraphs. Write in past tense: you are not telling your reader what to do, but

---

passages: Conservation genetics of Arctic Island wolves. *Conservation Genetics 9,* 879-892.

rather describing what happened during your experiment. Trust that your reader is smart enough to extrapolate a stepwise procedure on their own.

Do not provide a list of materials, either in bullets or in sentence form. Materials should be mentioned when describing how they were used.

Example:

Purpose of the procedure is concisely identified.

The materials (potato, blender, water) are mentioned when they become relevant to the method.

To prepare the catecholase extract, a potato was skinned, washed, and diced. Using a kitchen blender, 20.0 g of diced potato and 150 mL of distilled water were blended for approximately 2 minutes. The resulting solution was filtered through four layers of cheesecloth and the extract was stored in a sealed, sterile container.

Similarly, the Spectronic 20 is not mentioned until it is used.

The wavelength of a Spectronic 20 spectrophotometer was set to 540 nm. A control tube containing distilled water, pH 7 buffer, and catecholase extract (Table 1) was used to calibrate the spectrophotometer at zero absorbance.

Four concentrations of catechol substrate were prepared by mixing different volumes of 0.1% substrate solution with pH 7 buffer and distilled water (Table 1). 1.0 mL of catecholase extract was added to each tube immediately before insertion into the spectrophotometer. For each tube, absorbance was recorded at time zero (t=0), then at one-minute intervals until ten minutes had passed (t=10).[6]

---

[6] Adapted from "Writing Biology Laboratory Reports" by Molly Cage and Jonathan Wakefield, with Beth Brandler, Bruce Ingersoll, Jefferey Lewandowski, and Daniel Hocutt. http://writing2.richmond.edu/training/project/biology/biology.html

Example for Chemistry:

Materials

Food-grade food color additive FD&C Blue#5 [ALDRICH] was used without purification. Only deionized water was used to make eight aqueous solutions of the food additive over a concentration range of 10^{-6} to 10^{-2} M. An additional aqueous solution of the food additive of unknown concentration was provided. A Cary14 UV-VIS spectrophotometer was used to measure the absorption of the food additive solutions.

Methods

Aqueous solutions of the food additive were prepared by weighing the required weighed amount of food additive powder on an analytical balance, adding to a 100-mL volumetric flask, and adding deionized water to first dissolve it completely, before filling the flask to the mark.

UV-VIS measurements were made at room temperature, at a wavelength of 565 nm, and using a glass cuvette with a path-length of 1.0 cm.[7]

> **CHEM:** Materials are often described in a separate subsection of the Experimental Procedure section. This is because it may be necessary to purify or prepare materials before beginning the main experiment. Use this option to make the Methods subsection simpler and easier to follow.

2.5.2 Writing for Clarity

Assume that your reader was not present during the experiment, and therefore will not know what lab notations or codes represent. Avoid non-specific labels like "tube 1" or "condition A" in your text and figures or tables. Instead, use clear descriptors such as "control condition," "catecholase reaction with inhibitor," or "transformation tube" to distinguish treatments in the experimental design.

---

[7] Singfield, K. (2016).

Be aware that all descriptors must be defined and thoroughly explained before use: do so in the text as each procedure is described. In complex experiments, a table can be used for easy reference.

Example:

A Spec 20 was used to measure A600 of Tubes 1, 2, and 3 immediately after chloroplasts were added (Time 0) and every 2 min thereafter until the DCIP was completely reduced. Tube 4's A600 was measured only at Time 0 and at the end of the experiment.

> This example introduces materials (e.g. Spec 20, chloroplasts) as they are used, which is correct. However, the reader will not understand the significance of designators like "Tube 1" without referring back to previous explanations (if any are given).

> In this version, notice how identifying the controls and treatments (bold) has clarified the meaning of the passage, even when it is taken out of context.

A Spectronic 20 was used to measure A600 of the **reaction mixtures** exposed to light intensities of 1500, 750, and 350 uE/m^2/sec, immediately after chloroplasts were added (Time 0) and every 2 min thereafter, until the DCIP was completely reduced. The A600 of the **no-light control** was measured only at Time 0 and at the end of the experiment.

2.5.3 Choosing an Appropriate Level of Detail

A common error when writing the Materials & Methods section is including too little detail. Do not assume your reader has access to your lab manual: in other words, writing "See manual for procedures" will not be sufficient. You must describe your experiment in your own words. **It is especially important to note any changes made to the protocol during the experiment.**

PHYS:
A reference to the lab manual may be sufficient, provided no changes to the procedure were made. Any changes, however, must be fully described in this section of the report. If uncertain, always check with your professor.

An equally common error is the tendency to include too much detail: **a Materials & Methods section should be concise and focused as well as thorough.** A guiding principle is to assume that your reader has the same level of knowledge that you have: good practices and standard protocols will go without saying. To strike the right balance, ask yourself:

- whether the steps described are considered common knowledge (e.g. that gloves should be worn while handling bacterial cultures), and
- whether altering a particular material or method would change the results of the experiment (e.g. using a match to light a Bunsen burner instead of a flint striker).

Example:

This is a wordy and over-written description of a simple procedure commonly used in cell biology. Notice that a single action is described per sentence and lots of unnecessary details are given.

The petri dish was placed on the turntable. The lid was then raised slightly. An inoculation loop was used to transfer culture to the agar surface. The turntable was rotated 90 degrees by hand. The loop was moved lightly back and forth over the agar to spread the culture. The bacteria were then incubated at 37°C for 24 h.

This example provides all of the critical information, but is much more concise.

Each plate was placed on a turntable and streaked at opposing angles with fresh bacterial culture using an inoculating loop. The *E. coli* were then incubated at 37°C for 24 h.

2.6 RESULTS

The purpose of the Results section of a lab report is to present experimental observations as clearly, simply, and succinctly as possible. In many cases, this will involve using a combination of tables and/or figures as well as text.

PHYS:
Results is sometimes called "Data & Analysis."

Decide which method(s) of displaying data will be most effective and construct your tables and figures before beginning to write.

CHEM:
Professors may request that Results and Discussion be combined into a single section. In these cases, discuss each result as it is presented.

2.6.1 Tables and Figures

Tables and figures are used to display complex data in academic papers: tables and figures should *not* be used to display data that could be summarized in a few sentences. Each table or figure should be clearly constructed and easy to interpret, and should contain enough information that its contents can be understood without reference to the text. The text should be used to draw attention to extremes, trends, and other key features of the data, rather than simply repeating details the table or figure provides.

2.6.1.1 Tables

Use a table when it is important to show precise values, or to facilitate comparisons between groups.

Table captions (labels) are placed *above* the table. Captions should include:
- table number, and
- an informative title.

Any additional details necessary for understanding the data can appear above or below the table, depending on the style being followed. These details may include:

- a brief description of table contents,
- explanations of any abbreviations used in the table, and
- citations for any non-original data.

When organizing data:

- label columns and rows clearly,
- arrange discrete variables in columns instead of rows, and
- organize variables in a logical order, to be read from left to right. Putting the independent variable in the first column, followed by data for dependent variables, is usually a good strategy.

If the table includes numerical data, always:

- indicate units, and
- use a consistent display format (e.g. number of decimal places).

Example of a bad table:

Data is arranged in rows instead of columns, making it harder to understand.

Labels are unclear – e.g. change in what? Units are missing.

Year	2007	2008	2009	2010
Wage	7.60	8.10	8.60	9.65
Change	0	6.17	5.81	10.88
Inflation	0	1.16	1.32	2.35

Table 1. Wages and inflation.

Caption appears below table, instead of above.

Caption does not explain what region the data comes from, or category of wage it represents.

Example of a good table:

Table 2

Changes in Nova Scotia's minimum wage relative to Canada's inflation rate

Year	Minimum Wage ($)	Increase (%)	Inflation Rate (%)
2007	7.60	--	--
2008	8.10	6.17	1.16
2009	8.60	5.81	1.32
2010	9.65	10.88	2.35

Note: Minimum wage data obtained from the Government of Canada's Labour Program website. Inflation rate data taken from inflation.eu.

> Table 2 is well organized and clearly labeled. Enough information is provided that the data and its significance can be understood from the table alone.

2.6.1.2 Figures

Figures are visual displays of data such as photographs, illustrations, maps, or graphs. All types of figures should have captions (labels) that:

- appear *below* the figure,
- include a figure number and informative title, and
- provide any additional details necessary for understanding the data, such as:
    - a brief description,
    - explanations of abbreviations, and
    - citations for any non-original data.

Graphs are a common type of figure used to make comparisons, show trends, or reveal relationships in the data. The type of graph used depends on the nature of the data, but in general:

- axes must clearly labeled,
- units should be given in the axis label, not the scale,
- a legend or key must be included if multiple data sets are shown, and
- colour should only be used for complex graphs that cannot be understood in black and white.

PHYS & CHEM: Many professors require graphs that display error bars, fit, uncertainty of fit, and R^2 values. Follow instructions carefully.

Example: bar graphs are used to compare independent values

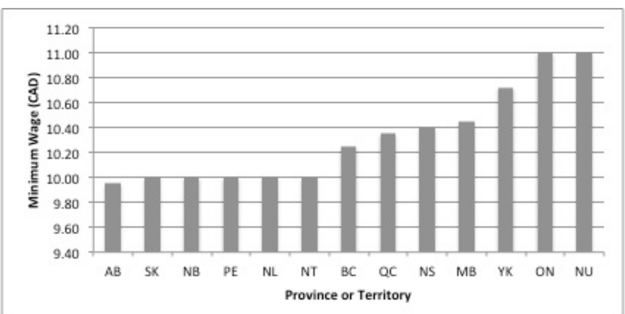

Figure 1. Comparison of Canadian minimum wages in 2014. Data from www.retailcouncil.org.

Example: line graphs show the relationship between two variables

Captions of a single sentence may be enough for simple figures.

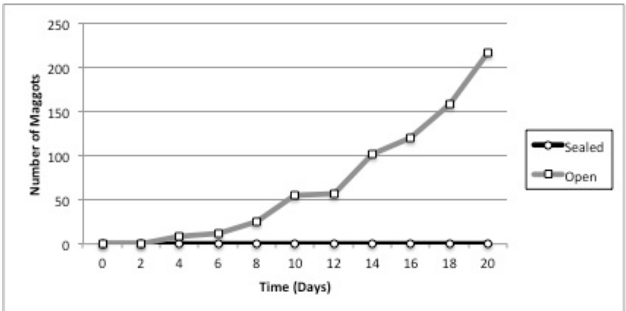

Figure 2. Number of maggots observed on steak samples contained in sealed or open jars.

Example: pie charts compare proportions of a total

A sentence summarizing the main result may also be enough.

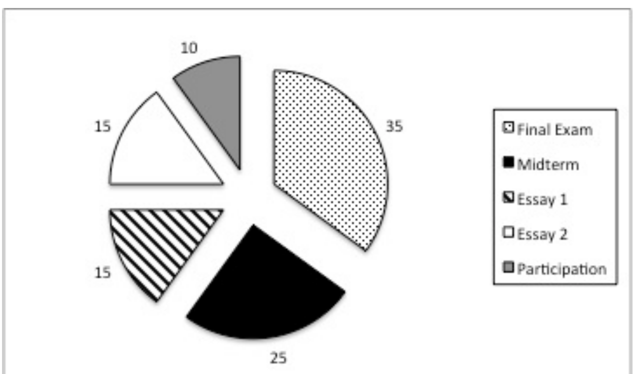

Figure 3. The final exam is the largest contributor to the final grade (%).

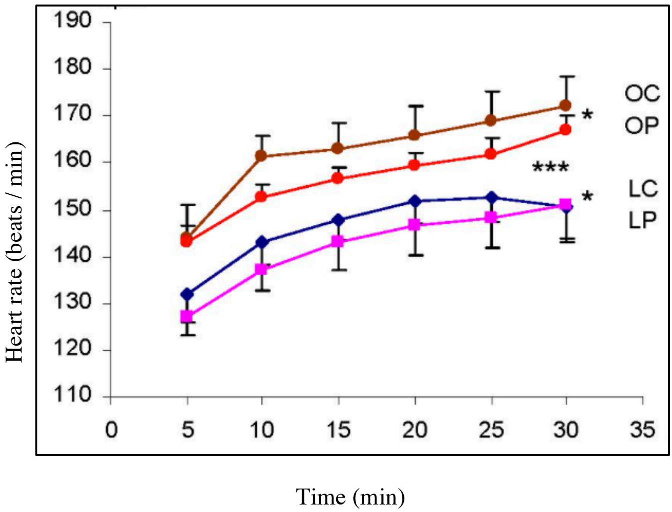

Figure 4. Caffeine increases heart rate in lean and obese subjects during exercise. Mean values (±SE) of heart rate recorded every 5 min throughout the treadmill exercise in lean (n = 6) and obese (n = 6) men following caffeine or placebo ingestion. O - Obese; L - Lean; C - Caffeine; P - Placebo; * Significant (p<0.05) overall difference between caffeine/ placebo trials; *** Significant (p<0.001) overall difference between lean and obese subjects.[8]

Complex data requires longer captions in order to be understood. All symbols must be defined. Including choice details from the Methods is also helpful.

If your figure has multiple panels, provide a general description of the figure, followed by details for each panel.

[8] Figure and caption adapted from: Farhad, R., M. Bahman, D. Arsalan. (2009). Effect of caffeine on metabolic and cardiovascular responses to submaximal exercise in lean and obese men. *Biomedical Human Kinetics 1(1)*, 31-35.

2.6.1.3 General Tips for Using Tables and Figures

Do not present the same data in both a table and a figure, unless specifically told to do so. Choose the form that will be most effective for your type of data.

Number tables and figures separately and sequentially.

> *Example: Table 1, Table 2… and Figure 1, Figure 2…)*

Guide the reader to relevant tables or figures by referencing them in the text.

> *Example of a poor table reference:*
>
> Table 1 shows the summary results for male and female heights at SMU. On average, males were taller than females.
>
> **Total word count: 20**

The first sentence of this paragraph tells the reader that data appear in Table 1, but a second sentence is required to indicate the features or importance of this data.

Example of a better table reference:

Table 1 shows that average height for males at SMU is higher than for females.

Total word count = 15

This single sentence not only draws attention to a key feature of the data, it refers the reader to the table for further information.

Example of a good table reference:

On average, males attending SMU are taller than females (Table 1).

Total word count = 11

This sentence is even shorter than the second example, but contains all the same information. A guiding principle for science writing is to pack maximum information into the fewest words possible: this allows the reader to focus on key data, without bogging down in loose or fluffy sentence structure.

2.6.2 Writing the Text of a Results Section

Do not repeat every value shown in a table or figure in the body of the Results section. Instead, use the text to draw attention to key features, extremes, or trends in the data, while referring the reader to the relevant table or figure for details.

It may be necessary to reference materials or methods in the Results section of the report, so that the reader understands which procedure produced which observations. **As much as possible, however, minimize repetition between sections: the focus of the Results section must remain on the data.**

PHYS: Numerical data and calculations are sometimes presented in a separate Data & Analysis (Results) section. Text descriptions are provided later, in the combined Results and Discussion section.

Similarly, avoid the temptation to analyze, interpret, explain, or otherwise discuss what occurred during the experiment(s). **The Results section is a straightforward account of observations, given without additional commentary.** If data are presented clearly and in a logical order, the reader will begin to draw his or her own conclusions even before reaching the Discussion section of the report.

Example Results Paragraph:

The underlined portion references the Materials & Methods section, reminding the reader which part of the experiment produced this result, without going into unnecessary detail.

Within experimental broods, orange chicks were fed at a higher rate than black chicks (Figure 2d; Wilcoxon test, $z = 3.48$, $P < 0.001$) **demonstrating that parents prefer ornamented chicks. As a result of their enhanced feeding rate,** orange chicks grew more rapidly (Figure 2e; Wilcoxon test, $z = 2.83$, $P < 0.005$) and enjoyed higher survival rates than black chicks in the same brood (Figure 2f; Wilcoxon test $z = 2.77$, $P < 0.01$).

The bolded portion provides interpretation and synthesis—the phrases "demonstrating" and "As a result" indicate that the author has drawn conclusions based on the experimental data. These conclusions, however, belong in the Discussion section of the report, and should be removed from the Results.

Figure is concisely referenced. Analysis is presented, rather than raw data.

2.6.2.1 Tips for Effective Results Sections

Present results in a logical order. For example, if the goal of the study is to evaluate the effect of an experimental diet on bone density in rats, start by describing data from rats fed the control diet. Once this foundation has been established, present data from the experimental group.

Present unexpected results and/or those which do not support the hypothesis. If the experiment was properly conducted, all data is valid and important. Unexpected or negative results may also identify flaws in the experiment or prompt further research.

Report analysis of the data, rather than the data itself. For example, present means, percents, or other summary statistics in the text. Raw data can be provided in an appendix if required. Always use appropriate units (e.g. "The mean length was 10 m").

Use transitional words and phrases to show connections and patterns in the data (e.g. in contrast, in addition, however, furthermore…).

Example Results Section:

Notice how the author uses the text to draw attention to the most important features of the data. The reader is referred to the figure for less-important details.

When ground plants were exposed to light wavelengths below 560 nm, CO_2 absorption remained low and relatively steady (Figure 2). However, absorption increased rapidly beginning at 580 nm and peaked at 740 nm before dropping off at higher wavelengths. In contrast, two absorption maxima were observed for canopy plants, one at 480 nm and one at 740 nm. Canopy plants also absorbed the least CO_2 at 580 nm, the same wavelength at which absorption in ground plants began to increase.

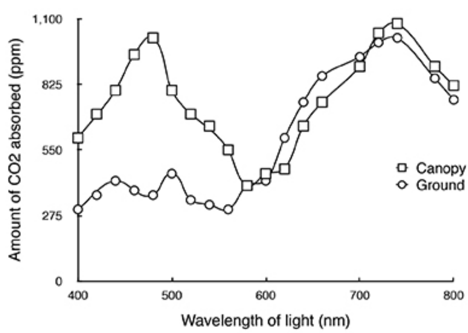

Figure 2. Photosynthetic response to various wavelengths of light for rainforest plants. Leaf tissue was isolated from canopy trees or ground shrubs. Leaf tissue was sealed into a respiration chamber, where the leaves were exposed to a controlled amount of filtered light. Photosynthesis was estimated by measuring the amount of CO_2 absorbed in 10 minutes. Each points is an average of 10 isolates.

2.7 DISCUSSION

The Discussion section is the final section of most lab reports or scientific papers. A well-written Discussion:

- interprets the results of the experiment,
- places the results in the context of previous scientific thought, and
- acknowledges uncertainty, limitations, and sources of error in the experiment.

You should also treat the Discussion as an opportunity to demonstrate to your professor that you have a thorough understanding of the experiment and the scientific theory or principles it was meant to demonstrate or test.

The Discussion section will generally follow the same outline as the Materials & Methods and Results sections (i.e., discuss the first result first). Data that was not described in the Results section should not be mentioned in the Discussion.

2.7.1 Interpreting the Results

Generally speaking, each paragraph in a Discussion section will deal with a single result. Briefly remind the reader of each result, without repeating unnecessary detail. The Discussion should provide more than a recap—it should interpret the data, **explaining why particular observations were made and what they might mean.** The goal is to use the data to draw conclusions about the hypothesis or research question under investigation.

CHEM: Professors may request that Results and Discussion be combined into a single section. In these cases, discuss each result as it is presented.

PHYS: For simple experiments, combine Results and Discussion in a single section to avoid repetition. For complex experiments in advanced courses, results and discussion will be extensive, and should therefore be separated. Remember to include the consistency check where appropriate.

It is often helpful to envision yourself as a lawyer in a courtroom drama, building a case for a particular interpretation of the evidence. Present your arguments clearly and concisely. The reader will be more likely to agree with your conclusions if they are well-supported and easy to understand.

Where appropriate, use previously published information on your topic to support your conclusions. Always cite your source (see section 2.10).

Example:

Underlined portions of the paragraph remind the reader of key results.

The striking behavioural improvements seen in the treated individuals were **due entirely to functional restoration in the treated eye**, as dogs consistently failed to avoid obstacles when the treated eye was covered. **This also demonstrated that rAAV treatment in one eye does not lead to improved visual function in the contralateral eye in the dog model.**[9]

Bolded portions provide the authors' interpretations of these results.

[9]Le Meur, G., Stieger, K., Smith, A. J., Weber, M. Deschamps, J. Y., Nivard, D., et al. (2007). Restoration of vision in RPE65-deficient Briard dogs using an AAV serotype 4 vector that specifically targets the retinal pigmented epithelium. *Gene Therapy 14*, 292-303.

2.7.2 Placing the Results in Context

The Discussion section should place the results of the experiment within the context of previous scientific thought. **Show how the experiment supports, contradicts, or adds to what was already known, explaining *why* the results are important and worthy of consideration.**

The Introduction of the report shows the state of scientific knowledge prior to the experiment; the Discussion shows how the results of the experiment have advanced that knowledge. Use the Discussion to answer any questions raised in the Introduction.

> *Example:*
>
> <u>The activity of the salivary enzyme amylase increased with increasing temperature, reaching a maximum at 70°C (Figure 1).</u> *Most enzymes become denatured at temperatures above 50°C (Perkins, 1964), but in this experiment, amylase appeared to function best well above this point.* **One explanation for this unusual result is that mouth temperature can vary during eating, thus requiring a high degree of heat-resistance in the amylase enzyme. It is also likely that increasing the temperature had a direct effect on the reaction rate; the rate of chemical reactions usually increases with temperature because additional energy is present in the system (Stryer, 1995, p. 46).**[10]

Key result is underlined.

Use of previously published scientific literature shows that results from this experiment are unusual (italics).

The authors present two possible explanations for their data (bold). Note that these two explanations could both be true at the same time.

[10]Adapted from "The Structure of Scientific Reports" (UniLearning) http://unilearning.uow.edu.au/report/2bvi1.html

2.7.3 Limitations and Sources of Error

NOTE:
Many experiments include sources of error that are not mistakes: e.g. variations between instruments or imprecise measurements.

There are several reasons why experiments produce unexpected results. In first- and second-year courses, when students are learning lab techniques for the first time, mistakes when conducting the experiment are most likely. Taking good notes during the lab will help you address these sources of error when writing your Discussion section.

PHYS:
The Discussion should address between one and three relevant sources of error, in addition to any mistakes.

However, listing all possible ways the experiment could have gone wrong is counter-productive. **Instead, explain how a particular source of error could have produced the specific result you observed.** Demonstrating that you understand the scientific principles at work is critical.

In other cases, results may not support your hypothesis because the hypothesis is incorrect, or because the methods are a poor match for the research question. If your conclusions contradict those of other scientists, consider differences in experimental design (e.g. controls) as well as possible errors made while conducting the experiment. Again, be sure to explain how differences in method could explain the specific result you observed.

NOTE:
Limitations and errors are not present in every experiment. Only include this kind of information where appropriate and necessary.

Finally, experiments may fail because they are unable to distinguish between multiple possible explanations for a particular phenomenon. This is not an error, per se, but rather a limitation of the experimental design. In these cases, you may suggest additional experiments that will tease apart the possibilities and resolve any uncertainty.

Example:

Four factors suggest that genetic identity of wolves TU9291 and SH9201 is not simply due to error. The samples were submitted to biologists nine months apart, in separate towns, by separate local hunters, and thus could not have been confused during initial collection and processing. Both samples consisted of tissue taken from whole skulls, eliminating the possibility that a hunter could mistakenly submit two samples from a single wolf. The sample identification numbers are visually distinct, reducing the risk of mix-up. Finally, the 14-locus genotypes used here were a composite of data from Carmichael et al. (2001) and from amplifications of additional loci performed using fresh DNA extractions of the original tissue (Carmichael et al., 2007a); laboratory error producing spurious identity is therefore unlikely.

The introduction of this report appears on page 19. Recall the hypothesis that these wolves are twins.

Potential sources of error are identified and eliminated.

In 1999, Neff et al. found one set of verified monozygotic twins during pedigree analysis of approximately 200 domestic dogs (*Canis familiaris*). The occurrence of one set of monozygotic twin wolves in a sample of over 2000 individuals is therefore reasonable, and seems the most likely explanation for the genetic identity of TU9291 and SH9201.[11]

Published literature is used to support the authors' conclusions. Note that the source is paraphrased and cited.

[11] Adapted from Carmichael et al. (2008) Monozygotic twin wolves with divergent life histories. *Arctic 61(*30), 329-331.

2.9 Conclusions

PHYS:
The consistency check must be restated in the Conclusions.

In some scientific disciplines, lab reports include an additional section, called Conclusions. Summarizing the main conclusions or “take away” of the report, this section is never more than a paragraph in length.

If your professor does not require a Conclusions section, you may wish to end your Discussion with a few sentences that deliver a similar “bottom line.”

2.10 Citing Your Sources

PHYS:
Use square brackets for citations, to avoid confusion in writing equations.

A well-written formal lab report will always include references to previously published work, most commonly in the Introduction and Discussion sections. In-text citations (citations in brackets) are used within the body of the report to identify facts and ideas paraphrased from research sources. A reference list must also be included at the end of the report, providing full bibliographic information for every source consulted.

NOTE:
Your professor may request a citation style not listed here. Whatever style you use, be sure to apply it consistently.

A large number of citation styles are used in the sciences, all with their own requirements for level of detail and placement of punctuation. Use the correct style for your discipline, or follow your professor’s instructions:

- Biology – Canadian Science Editors (CSE)
- Chemistry – American Chemical Society
- Environmental Sciences – APA
- Physics – Physical Review Letters

Style guides can be obtained from the Writing Centre, the library, or online. You may also wish to invest in reference management software, such as RefWorks, Mendeley, or Endnote.

2.10.1 Commonly Asked Questions

Do I have to use a citation after every sentence? All information taken from previously published work must be cited. In paragraphs where multiple sources are used, it may be necessary to cite every sentence. However, if several, back-to-back sentences rely on the same source, a single citation is sufficient. For entire paragraphs that draw on a single source, cite the first sentence and the final sentence, forming "bookends" for the content (it should also be clear from the text itself that the paragraph describes a single study).

When it comes to citing sources, the key is to ensure that the reader can clearly identify which material is original and which material came from previous research.

What is common knowledge, and do I need to cite it? Common knowledge consists of information that is generally accepted as true. "DNA is a double helix," and "Atoms contain protons, neutrons, and electrons," are examples of common knowledge, which does not need to be cited. In contrast, facts, data, and ideas that are unique to a particular study must be referenced to that source. A good rule of thumb is to cite all information that would not appear in *every* introductory textbook on your topic.

What if it was my idea originally, and then I read it somewhere? If you have a published source that includes the information, always cite the source, regardless of whether you independently generated the same idea.

How do I paraphrase a number? Numbers and measurements cannot be paraphrased – they are unalterable facts. Focus on changing words and sentence structure instead.

Part 3 – Appendix
Course-specific checklists

Section titles used in each discipline are listed here for easy reference. Be sure to consult Part 2 for details on each section. Note that your professor may request modifications not described in this guide: always follow the instructions on your assignment and direct any questions to your professor.

3.1 Biology

Title
Abstract
Introduction
Materials & Methods
Results
Discussion

Reference List in CSE format

3.2 Environmental Sciences

Title
Abstract
Introduction
Materials & Methods
Results
Discussion

Reference List in APA format

3.3 Chemistry

Title
Abstract
Introduction
Experimental Procedure
Results
Discussion

Reference list in American Chemical Society format

3.4 Physics

NOTE:
Follow your professor's preferences for section headings and breakdowns.

Title
Abstract
Introduction (Theory)
Materials & Methods (Apparatus & Procedure)
Results (Data & Analysis)
Discussion (Results & Discussion)
Conclusions

Reference list in Physical Review Letters format