Undergraduate's Guide to Writing Chemistry Papers

Fall 2014 Version

Table of Contents

1

Introduction to Scientific Writing

1.1 Approaching scientific writing

Before we can begin discussing how to approach the scientific writing that you will do in this course, we must first preface with a little bit of background about this type of writing.

1.1.1 Why do we write?

Why does a scientist need to write? If you ask most scientists, they'd probably prefer to avoid the writing altogether and focus solely on the actual science. That said, when pressed, they will admit that it is also one of the most crucial and time-consuming parts of what they do. Communication about scientific results is absolutely essential to the enterprise of science. Discovery without communication is pointless.

There are many different types of writing that a career scientist engages in. Grant proposals are the main vehicle by which scientists petition funding agency for money to maintain their research programs. A researcher will spend a significant portion of time and effort writing grants and, if they are successful in acquiring funding, they will have to write periodic progress reports and summaries to the agencies.

Once the experiments are complete, the final step in the *Scientific Method* involves the dissemination of findings (communicating the results). In general there are two different, but simultaneous, approaches that a researcher will take in order to spread his work into the greater scientific community: (1) make oral presentations at conferences, and (2) publish scholarly papers.

Publication is considered the most desirable and necessary method of communication as it creates an accredited record of the results and allows for the greatest dissemination of the information across both distance and time. In general, the purpose of publishing a scholarly paper is to convey the findings of an experiment(s) that has been performed (primary), to persuade the greater scientific community to adopt one's own perspective on a given topic (secondary), and to justify the funding that has been received (tertiary).

Scientific research is a team sport. After individual research groups perform experiments, and those experiments are validated and duplicated, they attempt to persuade others to accept or reject their hypotheses by presenting and interpreting the data. The scholarly paper is the vehicle of persuasion; after it has been published, it is available to other scientists for review. If the findings stand up to criticism, they become part of the accepted body of scientific knowledge until they are later disproved.

These scholarly papers make up the *primary sources* in the scientific literature[1].

1.1.2 What do we write?

A research scientist will never write a 'Lab report.' While it is unclear as to the exact historical origin of the dreaded lab report, it is clear that only students in science courses are ever asked to produce these ridiculous types of papers. The sole goal of the lab report is to convey the specific findings that a student achieved in a pseudo-scientific situation, where the outcome of the experiment is well-known and documented, to a teacher looking for the results. Outside of undergraduate instructional courses, this type of paper simply does not exist. These papers are absent of any scientific motivation (clarification: a grade is not motivation) and a plagued with stylistic horrors that are designed to streamline the grading process.

Whatever the history, or reasons, behind the lab report, it is clear that it is not a genuine form of scientific communication. It is for this reason that we do not believe in teaching that form of writing. Instead, we will focus on developing the skills necessary to formulate a cogent and persuasive scientific argument in a manner that is consistent with the writing found in *Journal Articles*, the most ubiquitous vehicle of scientific communication in the literature. Some, but certainly not all, of the major differences between a lab report and a journal article are:

- *Motivation:* in journal articles, the Introduction will typically include a significant amount of details about the motivation behind the project/experiment. Here, motivation refers to an over-arching reason why the science, or the specific outcome, has global ramifications and interest. Why were the researchers interested in pursuing this research? Why were funding agencies willing to fund the research? And why might other people be interested in the results? In lab reports, students are not motivated by external factors; rather, they are performing a 'cookie-cutter' experiment that is mandated by faculty for the sole purpose of getting a grade.

- *Methods:* the experimental protocol described in a journal article is a novel approach, or variation on an approach, that is being published. For students writing lab reports, however, the formulaic laboratory procedure is not novel and usually does not need to be presented in such detail. Certainly, routine tasks like cleaning glassware or titrations would never be described in the scientific literature.

- *Sample calculations:* many instructors prefer to see a student's sample calculations and raw data presented in the Results section of lab reports. Neither calculations nor raw data are ever presented in the body of a true scientific paper or journal article. Rather, the important formula are presented along with the final results, and the rest of the information (data and calculations) will be presented - in the rare occasions that they are sophisticated enough or interesting enough to be included at all - in the Supporting Information section (more on this later).

- *Arguments vs. data dump:* the writing in journal articles must be extremely persuasive, as the entire function is to promote a set of findings on the broader scientific community. When discussing the validity and consequence of these results, it is critical that the argument presented be persuasive. Lab reports, however, are usually seen as a vehicle for the dissemination of a student's results to an instructor. As such, it is rarely necessary for the student to justify results, rather simply that they be presented. A note of caution: many students understand the need to be persuasive to include justifying getting bad results. Instead of claiming that a bad result is acceptable, consistent, etc..., you should simply present an argument as to why you may have received the erroneous results. Additionally, reports of bad results would never actually get published in the literature. Nor would anyone try to publish them. This is another distinction between classroom and real-world writing.

[1] We will explicitly discuss the literature, and how it is used, in later assignments.

- *Appropriate references:* when writing scientific papers, previous work and background information are always referenced. The most appropriate sources for references are other journal articles (in peer-reviewed journals), books, and scientific databases. Internet references are not appropriate for scientific papers. Here, "internet references" refer to private websites or non-peer-reviewed information sites (such as Wikipedia or WolframAlpha). Books accessed online (such as through Google Scholar) or journal articles found online are **not** considered internet references. If another reference **cannot** be found, the internet can be used sparingly, if ever.

In general, freshmen chemistry labs are not well suited to the type of scientific writing that we will be exploring in this course. That said, this course focuses more on quantitative analysis, where the outcome of each experiment is much more student, and sample, dependent. Consequently, the inquiry approach and nature of the course opens up the possibility of writing our experimental reports in the journal article style. It should be mentioned, however, that the journal articles that you will be writing will, clearly, not have the same scope or depth as those in the actual literature.

1.1.3 To whom are we writing?

Possibly as important as the content of the paper is knowing who will be reading the paper - the *Audience*. Scholarly papers are always written with specific audiences in mind. These are often determined by the type of publication; for example, the Journal of the American Chemical Society is going to attract a more specialized audience than Scientific American. Scientists must gear their writing toward their particular audience in order to have the greatest impact. The main potential audiences of a scientific work are as follows, in order from most knowledgeable to least:

1. *Experts*: these are people with expert knowledge of the general field of chemistry on the whole and advanced knowledge of the specific sub-discipline (such as biochemistry, computational chemistry, etc...). Journal articles and communications are generally written for this audience.

2. *Scientific*: while not experts in the specific sub-discipline, or even the discipline, of the author, these readers are experts in another scientific field; such as biology, physics, or mathematics. Most scientists try to keep current on the major breakthroughs in other field and will therefore read select journal articles, usually in the cross-discipline journals such as Science and Nature.

3. *Student*: this is you. Writing for a student audience is designed to instruct individuals starting at a basic level. Textbooks and lab manuals are good examples of writing done with a student audience in mind.

4. *General*: the general audience includes all readers, regardless of background, who are interested in the field. Often readers will have no training whatsoever in the discipline, but are interested in the topic. News articles and popular science articles are good examples of works written for a general audience.

Each specific audience requires the writer to be aware of the limitations and the expectations of the readers. There is very little assumed knowledge when we write for a general audience - meaning that we would be careful to explain all pertinent concepts and procedures in explicit detail. Conversely, it would be grossly inappropriate to include that same level of detail when writing for a scientific audience, much more so for an Expert audience. Similarly, the emphasis on motivation is likely to change for different audiences. A general audience is unlikely to care about a new laboratory technique that would be very exciting to other scientists.

There are two key differences between the type of writing discussed above and the realities of classroom writing that we need to discuss so that you can attempt to look beyond them:

1. Your audience (instructors and graders) are already familiar with the research goals and methods (and possibly even the expected results) of your experiments. Instead of trying to convince an unfamiliar audience of the validity of your research, you may feel that all you need to do is convince a familiar audience that you have properly performed an experiment that they designed. Our goal, however, is to help you develop an understanding of writing as it actually happens in the field of chemistry. Thus, you must imagine your instructor and graders not as figures in a class, but as representatives of a larger group of readers who belong to that particular academic area. Consequently, the vast majority of the writing we will do will be for the *scientific* and *expert* audiences. Specifically, you will write in the voice appropriate for an expert audience, but pitched at the scientific level commensurate with a scientific audience. Finding the correct balance of information to present for your desired audience is one of the more nuanced parts of scientific writing.

2. Unlike in an actual research setting in which you design your own research for some specific purpose, in a classroom you (mostly) perform the experiments given to you because that is what you are expected to do. This leads to the problem of understanding and communicating the purpose or motivation for the experiment, which is discussed in the next section.

1.2 Understanding Objectives and Motivation

For some students, it can be very difficult to correctly differentiate between the different levels of motivation and objectives in their labs. For each experiment performed we will look at the purpose, objective(s), and motivation.

1. Educational *purpose*: the (educational) purpose of a given experiment is the set of goals, and topics, that the *instructor* intends for students to learn from any given exercise. Clearly, this is not the motivation behind the *student's* performance of the experiment[2].

2. Lab *objectives*: these are the practical items that must be accomplished in the lab (create a standard curve, digest a sample, etc...). These are the objectives that students will list in their laboratory notebooks and they serve as the focus of the practical performance of the experiment.

3. *Motivation*: the over-arching goal of the science that is being studied. Rarely, if ever, will this be provided in the lab manual. The motivation for any given experiment is a good scientific, or humanistic, reason why the topic or substances being studied are of interest. This is the *Motivation* that you will need to provide in the Introduction sections of your papers or grant proposals.

To help sort out the differences between the lab objectives and the motivation of the experiment, it is helpful to use an objective/motivation statement: "We are ..... (lab objective) in order to ..... (motivation)." For instance, for a lab in which the density of pennies is measured, we might write: "we are measuring the density of pennies in order to determine the cost effectiveness of the US penny and determine whether it should continue to be made and kept in circulation."[3] Here, the objective is measurement of the density of pennies and the motivation is to ascertain whether or not the penny is a cost-effective form of currency.

[2]For the sake of argument we'll also assume that the student's objective is not simply to get an 'A.' Rather, that the student is interested in learning.

[3]We will never actually use this type of language ("we are") in the actual reports - only for the pre-writing assignments.

1.3 A general disclaimer

Students new to science, and science writing, almost always make the same mistake: they use overly complex terms/words (*e.g.* efficacious vs. effective; proximal vs. close). When students start reading the scientific literature, or even just science textbooks, many find themselves challenged by the depth and difficulty of the concepts being presented. It is very easy to mistake the difficulty of the science with complexity in the writing. In reality, scientists strive to write their complicated concepts in the most concise, precise, and simple language possible.

Worked example: Lab #1

Let's consider the first experiment that you performed and analyze it on the three levels mentioned above.

- *Educational purpose*: the main educational motives behind lab #1 were for the students to gain basic lab skill proficiency (pipettes, balances), learn about calibration (uncertainty, error), learn basic statistics (mean, standard deviation), gain confidence in the lab environment, and develop skills working problems with difficult unit conversions and dimensional analysis.
- *Lab objectives*: the two major objectives in the lab were to calibrate a micropipette and to determine Avogadro's number by performing the stearic acid monolayer experiment using the calibrated pipette.
- *Motivation*: very little was discussed about why Avogadro's number is so important to study. In fact, there are many possible correct answers and it is up to you to determine one or more.

1.4 End-of-chapter assignment

1. In your own words, briefly explain the differences between journal articles and lab reports.
2. For which audience do you think it is easiest to write? Most difficult to write? Explain, including a good reason for each of your choices.
3. Consider one of the labs that you recently completed: provide an analysis of the *Educational purpose*, *Lab objectives*, and *Motivation* of the experiment. Additionally, propose a valid objective/motivation ("we are ...") statement for the experiment.

2

Preparing Appropriate Exhibits

2.1 Developing a good argument

All writing is about making an argument – a dynamic form of rhetoric that is designed to answer questions (and pose new ones). In scientific papers, these arguments serve as a mode of disseminating the results of a few different types of scientific studies: developing new techniques and methodologies; studying a novel and interesting system; refuting/confirming previous results or beliefs; extending and refining previous work; and more. As scientific papers, especially ones in a strictly regimented field like chemistry, all of these different papers would share many structural and conventional similarities. Where these papers would differ substantially is in the argument being made.

Before we can begin to identify what makes a strong argument (which will be the subject of later chapters), we must first (a) figure out what our results mean and (b) format them as **Exhibits** that would be useful for making a persuasive argument.

Exhibits are the materials/items in your paper that you are offering for explanation, analysis, or interpretation. The most common exhibits are the results of the current body of work. In scientific papers with substantial amounts of data, these exhibits will often be presented as *figures* or *tables.* The remainder of this chapter will be dedicated to learning how to clearly communicate the results of an experiment in Tables and Figures – a highly underestimated, yet essential, skill to master.

2.2 Deciding on the use of tables and figures

It can be tricky to know how and when to use a table, a figure, or a graph.

- **Tables vs. Figures** - Tables are best used for data that are qualitative, data sets that include only a few points, or when you want to show the actual value of your measurements. Figures, and especially graphs, are used more as a way to visualize the trend of your data or the relationship between different sets of data.

- **How many figures to use** - This is extremely experiment-dependent. You may perform experiments in which only one table or figure is needed. The best criteria for determining if a table or figure is needed is your overall experimental goals; if the figure or table adds to your readers' understanding then it is necessary.

- **Placement in the document** - It is best to try to place your table or figure close to the text that refers to it. However, it is more essential that the table or figure is formatted properly rather than adjusting it to fit on a particular page.

2.3 General formatting guidelines for exhibits

2.3.1 Numbering

In a scholarly paper, all Figures, Tables, and Equations, are numbered sequentially (three separate sequences). These numbers (i.e. Table 1, Figure 1, Equation 1) are then used to refer to the figure in the text where you describe the data. Note: each type (Table, Figure, Equation) will have its own sequence.

Every table or figure should be referred to in the text that is in close proximity to the table or graph. That said, never use direction words, such as 'below' or 'above', to describe the location of Tables and Figures. When published, Tables and Figures are often moved at the printer's discretion. Since they are numbered in order and clearly labeled, a reader will be able to find them without you providing directions. Good reference statements might be: 'Table 3.2 shows the volume of water at various temperatures' or 'The molecular structures of the products are depicted in Figure 12.1.'

2.3.2 Titles

Every Table and Graph must be titled (equations do not have a title). The goal of a title is to tell enough information about the table/figure such that, in the context of your report, an outside reader can understand what the figure is showing. An example of a Table title might be: 'Table 1.1: Volume of 1.0 g of H_2O at Various Temperatures.' Table titles appear above the table.

For figures, the standard title that Microsoft Excel generates is not appropriate for our purposes in both format (above the figure, centered) and content. For figures, the title is simply the first part of the caption located below the figure, and should be descriptive and complete.

2.3.3 Captions

A good figure caption elaborates a little more on the information contained within the figure. Generally, a caption should be 1-2 sentences long and follow the title. The title should remind the reader of what data is being presented, while the caption should tell the reader any extremely pertinent information that would be needed to interpret the data being presented. In the case of a graph with multiple lines and no legend, the caption should serve as a legend (i.e. 'The trend before reaction (solid line) and after the reaction (dashed line)...').

Tables rarely have captions, unless there is a special note about the data. In that case a special character is placed in the table, for instance an asterisk ($*$) or dagger (†), and the note is placed below the table.

It is proper for captions to be single-spaced (even in a double-spaced document) and for the font size of a caption to be a little smaller than the rest of the text. In this way it is clearly identifiable what is a caption and what is body text.

2.3.4 Formatting Labels

Both tables and figures will have a label that will include its number. The label should precede the title (above tables and below figures). Many authors use the good practice of bolding the label: i.e., **Table 1**.

2.4 Effective use of tables

Most of the table formatting comes down to aesthetics. Your tables should have even column and row widths. In general, it is a good idea to offset the header row in some way (bold text or bold outlines). Where relevant, units are included in the column headers and not in the table cells.

Example 2.1: Table

Incorrect:

Table 3

Chocolate Brands	Type of Chocolate	Peak Absorbance	Concentration
Dove	Milk	0.956	1.912 ppm
Hersheys	Milk	0.855	1.71 ppm
Lindt	Dark	0.869	1.738 ppm
Cadbury	Dark	0.981	1.962 ppm

Correct: **Table 4.1** - Quantifying levels of caffeine in chocolate.

Brand	Type	Peak Absorbance	Concentration (ppm)
Dove	Milk	0.956	1.912
Hersheys	Milk	0.855	1.710
Lindt	Dark	0.869	1.738
Cadbury	Dark	0.981	1.962

Which one of these tables is clearer? Can you spot all of the difference between the two versions? Note that this is just one way to properly format a table.

2.4.1 What needs to go into a table

A good table should make the data easier to digest. Therefore, it is not necessary to make a table that will have a single column or row of data – that much could easily be presented in the prose without being too hard to grasp.

Conversely, students often start off by mistakenly presenting too much in their tables, perhaps in an effort to make them seem more significant. Masses of weighing jars, solids plus jars, initial temperatures, final temperatures, etc..., are all unnecessary *Raw Data* (the different types of data will be discussed in a later chapter). For now, it suffices to mention that raw data is never presented in papers (or even in supporting information for that matter).

2.5 Preparing effective figures

Figures can be a powerful way to present information in a visual medium. There are a few types of Figures that you may find useful to include in your scholarly paper:

- **Non-Data Figures** - You may be using or creating custom apparatuses for certain experiments. Instead of tediously describing the schematic of an apparatus, it may be easier to include a figure of the completed apparatus.

- **Crystal Structures** - A key step in synthesizing a compound is to determine its three-dimensional structure by slowly crystallizing a sample of the compound and irradiating it with x-rays. This is called a crystal structure. While you will not be determining the structure of any compounds this way, it can be informative to include any crystal structures of compounds you synthesize.

- **Graphs** - Graphs are the primary methods of presenting data in a visual manner. They allow the author to present substantial amounts of data in a compact way and allow the reader to perceive a trend in the information.

2.5.1 Graphs

When using data editing software, it is tempting to plot the graph and copy the resulting image into your document. Whether you use Excel or another program, most likely the default representation of the graph will not be sufficient to clearly present your data.

- **Graph Type** - You should choose the correct type of graph for the type of data you are presenting. While Excel's default is the bar graph, this type of graph may not be appropriate for the type of data being presented. *Bar graphs* are useful for presenting data to be contrasted, but that is not related. For data that shows a correlation (linear, or non-linear, trend), it is appropriate to use an *xy scatter* plot.

  In this course, most of your graphs will be *xy* scatter plots. Once you've chosen the correct graph type, most software allows the user to choose how the points are linked:

  - *No lines:* most graphs will not have connected points. Since you only measured a few data points in the experiment it is misleading to connect them by lines - this implies knowledge/data that is simply not there. Of course, it may still be appropriate to include a line of best fit (trendline) through the data.
  - *Smoothed lines:* the exceptions to the previous rule are chromatograms and spectra. Because both spectra and chromatograms are made by taking regular, and frequent, data points they are usually plotted using a smooth line (without markers / points).

- **Axes** - All axes need a label and units (if the measurement has units). There is no need to start the plot at point (0,0) unless that point is relevant to understanding the data (e.g. if you took a chromatogram between 400 and 700 nm, the x-axis range should be 400-700).

- **Dividing lines** - Excel especially likes to insert horizontal lines at the major y-axis tick marks. This is usually not relevant for most graphs.

- **Legend** - Legends are only useful if you are plotting more than one set of data on the same graph. Even then, identifying the individual plots can be done in the caption (if there aren't too many).

- **Using space properly** - You can resize the individual components of the graph to maximize the use of the figure within your final document.

2.6 Equations, Chemicals, and Values

- **Which equations are relevant?** - Numerical and chemical equations should be included if they are directly relevant to what you are doing. Relevant chemical equations include those that describe the chemistry you are doing. Numerical equations should only be used if they are relatively uncommon, and are involved with interpreting your data. Usually the entire derivation of an equation is not necessary.

- **Formatting chemical equations** - It should not need to be said that all mathematical and chemical equations should be formatted properly. This includes subscripts, superscripts, arrows, and chemical states (when applicable). While equations do not need a title or caption, they should have an equation number. For a good example of how to format an equation with a label, consult the examples in your lab manual.

Example 2.2: Equation

Incorrect: $Pb2 + +2Cl - -- > PbCl2$

Correct: $$\mathrm{Pb^{2+}}(aq) + 2\mathrm{Cl^{-}}(aq) \longrightarrow \mathrm{PbCl_2}(s) \tag{5.1}$$

Which one of these equations is better? Can you spot all of the changes?

- **Proper convention for chemical names** - Names of chemicals are not capitalized (HCl is hydrochloric acid, not Hydrochloric Acid).

- **Values and units** - It is proper convention to include a space between values and units.

2.7 End-of-chapter assignment

1. Look at Examples 2.1 - 2.4 in this document and explain the differences between the Correct and Incorrect versions of the Tables, Equations, and Graphs. (Graded on your first draft)

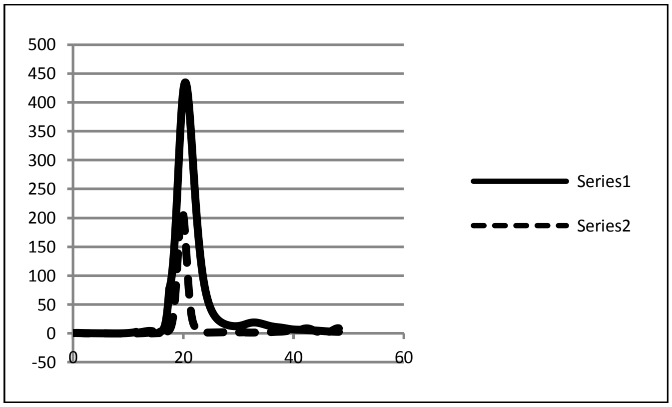
2. Explain how the choice of audience might affect the detail provided in figure captions.

3. In this course we won't be writing the traditional 'lab reports' (see Chapter #1 for differences between lab reports and scholarly papers). How might the amount/type of data included in a table be different in a lab report vs. a scholarly paper?

4. Consider a recent lab that required the preparation of at least one table and two figures (one spectrum and one trendline graph). Using the information in this handout, prepare an appropriate the table and figure. If the lab you selected only has one type of figure (spectrum or trendline graph), prepare the other type of figure for another data set. Don't forget to include Titles and Captions!

Example 2.3: Graph (1) - Chromatogram

Incorrect:



Correct:

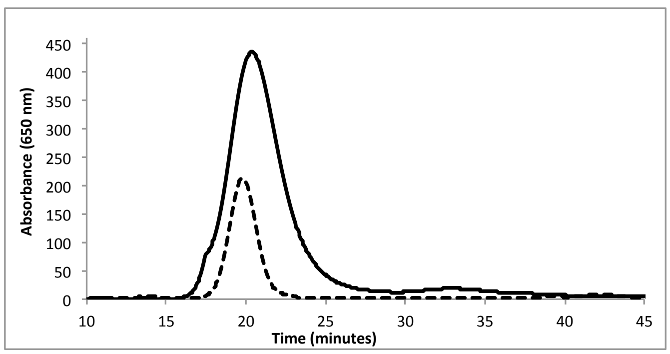
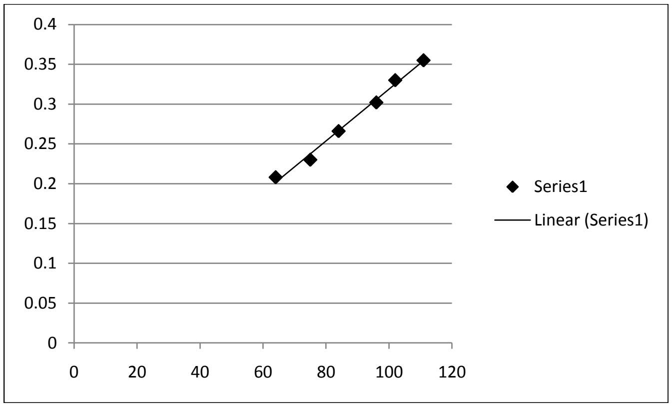


Figure 3.5 - HPLC Chromatograms of chocolate content remaining in socks after being washed with Washing Machine 1 (solid line) and Washing Machine 2 (dashed line). All absorbances were recorded at 650nm.

Which one of these graphs is better? Can you spot all of the changes from the generic Excel graph versus the properly formatted graph?

Example 2.4: Graph (2) - Trend Line

Incorrect:



Correct:

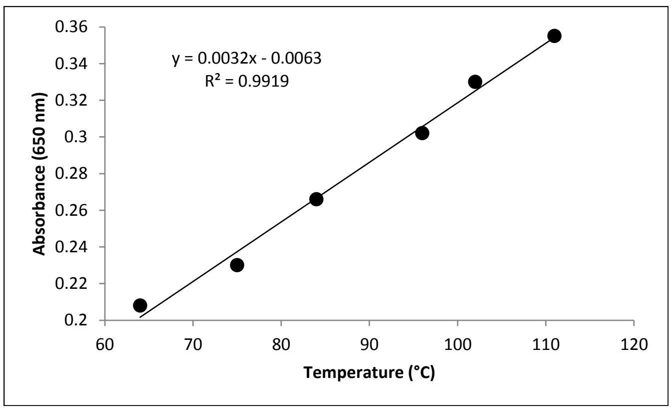


Figure 7.2 - Temperature dependance on washing machine efficiency. Peak absorbance at the maximum wavelength, 650 nm, is plotted against the temperature of washing.

Which one of these graphs is better? Can you spot all of the changes from the generic Excel graph versus the properly formatted graph?

3

Planning a Well-executed Scientific Paper

3.1 What makes a good argument?

All writing is about making an argument. Each field has its conventions regarding the structural and organizational details of research papers. Especially in a strictly regimented field like chemistry, these conventions dictate how papers are arranged and composed. That said, the common goal of all papers is that they be persuasive and, thereby, contribute meaningfully to how people think about a field. This is the *Argument*, and it is the most important aspect of writing a good paper.

In scientific papers, one of the most common types of arguments that are made usually takes the following form:

1. There exists an important area of science / life. (*Motivation*, in Introduction)
2. In that area, there is something missing or something that is inconsistent that needs to be investigated. (*Gap/Objective*, in Introduction)
3. The investigation was done using well-known, or rigorously developed, techniques/approaches. (Experimental)
4. The results of the investigation are important and substantive. These results either agree with previous understanding, are inconsistent with the current understanding of the field and require further explanation, or are presenting something entirely new. (Discussion)
5. Based on the results of the experiment, and possible future work, there will be broad impact on the field and, possibly, the world.[1] (Conclusion)

The general argument presented above is only one possible form of a scientific argument. Irrespective of the type of argument that you are trying to make, you will need to justify your assertions and claims through the use of sources in the primary (and secondary) literature and through the use of exhibits. Moreover, you will need to arrange and organize your thoughts into a meaningful story. The remainder of this chapter will focus on how to collect information, plan, and outline a strong argument that will lead to a well-written and persuasive paper.

[1] As we will discuss in the Conclusion chapter, rarely will lower-division undergraduate students do anything in a lab course that will change the world. That is ok - you can still pass.

3.1.1 Identifying sources that strengthen your argument

The biggest mistake made by novice writers is to decide on the argument that they intend to make *before* they've done their research and analyzed their results. This practice often leads to a very immature relationship with the scientific literature — these students will oftentimes write their entire paper before ever engaging outside sources (if ever).

A common question that teachers get is "how many sources do I need to cite?" Usually, this question is meant to illicit a number of sources that will not result in a penalty for not providing "at least 3 sources" (or however many the teacher is looking for). The problem is that this approach is very counterproductive. Instead of the students engaging with the sources (reading them and using the information as the basis of their papers), the students are just looking to put citations at the end of the paper. The real answer to the aforementioned question, as unsettling and frustrating as it may be, is that you should use cite all of the sources that you *actually consulted* when preparing your argument/paper, and no more.

In general, there are four categories of sources that are necessary to engage for any given paper: **B**ackground, **E**xhibits, **A**rguments, and **M**ethod/**T**heory (BEAM/BEAT). Each of these different types of sources is brought to serve a different function, which means that knowing how to identify them, as well as understanding their function, is paramount. The strongest writers will bring each different type of source, at the appropriate juncture, to support their arguments. While argument sources might be less common than the others, a healthy number of each of the remaining sources will help strengthen the argument and, hence, the paper.

- *Background*: These are the facts on which you are basing your arguments. Usually from the primary or secondary literature, these are treated as authoritative and are universally accepted. As students, a lot of this material may come from lectures. Sometimes, writers treat information gleaned from their background sources as "common knowledge," which means that they are sometimes un-cited. For the purpose of this course, material from lecture (and the lab manual) can be considered common knowledge. All other material must be cited appropriately.

- *Exhibits*: These are the materials that are offered for explanation, analysis, or interpretation. The most common exhibits are the results of the current body of work. In scientific papers, these exhibits will often be presented as figures or tables.

- *Arguments*: Argument sources are papers and books whose claims are being affirmed, disputed, refined, or extended in the current work. When citing these sources we are entering into a metaphorical conversation with other scientists. These types of sources are somewhat less common for the traditional undergraduate lab student, but are very common in the 'real' practice of science.

- *Method or Theory*: These are methods, theory, and approaches that are common to the field (of chemistry) and are used for performing the study or analysis. Usually from the primary and secondary literature, these are where the scientist derives their governing concept or an approach. The lab practices and techniques are also considered method and theory. Like background sources, method or theory sources can sometimes go un-cited, because they are often regarded as common knowledge.

The most important thing to remember is that 'sources' cannot be relegated to an afterthought. These 'sources' are the heart and soul of the claim that you want to make.

3.1.2 Seven questions to help craft your argument

Before you can even begin to think about what you intend to argue in your paper, it is necessary to (a) fully work-up your data and (b) survey the literature to find information relating to your experiment and results. Additionally, it is *highly* advisable that you take some time, after analyzing your data, before you start thinking about writing your paper. Take a 'step back' and look at your results with fresh eyes – this will help you see global trends, impacts, and ramifications. Then, use the literature to find sources that support, contradict, and explain your results.

Once you've analyzed your data, taken time to let that data settle-in, and researched in the literature, you are ready to start thinking about your argument. Consider the following set of questions that will help you decide on the argument you want to make. Note: they are not in the order that they will appear in your paper; rather, they are in an order that will be helpful for considering and planning your argument.

1. *What are the major conclusion(s) that you want to make?* Note: this is not the same thing as 'what value did you get?' Rather, you should think more globally about what your data means and what conclusions you can make based on them.

2. *What data do you have to support those conclusions?* Also, how do you intend to present that data? A table? A figure? Which data need be presented at all, and what belongs in the Supporting Information?

3. *What gap do these conclusions help fill in? What problem are you solving with these conclusions?* The first two questions help you formulate the major part of your argument and will guide you in the preparation of your Results and Discussion. This question - about the *Gap*[2] - is where you start to relate your conclusions to the motivation for the research.

4. *Why is that gap/problem important?* Once you've identified the gap that the research addresses (the previous question), it is time to start thinking about the *Motivation* behind the experiment.

5. *How are you going to fill in the gap or solve this problem?* Along with the previous two questions, this question completes the argument of the Introduction section of your paper.

6. *What limitations do you see to the conclusion(s) that you are trying to make?*

7. *How do these conclusions fill in the gap or solve the problem?*

One of the biggest differences between novice science writing and expert writing, is that novices often treat a paper as a linear argument, which starts with an Introduction and ends with a Conclusion. Experts, on the other hand, recognize that the argument being made should be circular – the end of the paper (the Conclusion) needs to answer/respond to the Introduction. This is the goal of the final two questions listed above: to revisit the *specific* motivation and goals of the experiment in the context of the results and conclusions.

Please note that there are two types of papers that you will write in this course: (a) full scientific research papers and (b) *abridged* reports. In abridged reports, which will not include Introduction and Experimental sections (only Results and Discussion, and Conclusion), the answers to questions #3-#5 will not be addressed directly. Nonetheless, without considering these questions, the argument made in the Results, Discussion, and Conclusion will not be strong.

[2]'Gap' refers to the specific lack in the scientific literature that is being addressed and the *motivation*/reason for doing the experiment. We will discuss the gap in greater detail when the Introduction section is discussed.

3.2 Preparing to write a paper that presents a strong argument

The most common mistake that novices make when beginning to write a paper is that they don't take the time to properly conceive the paper before they start "writing." Rather, most likely in the hopes of finishing quickly, they opt to start writing without properly organizing their thoughts or outlining the major points that they intend to convey. As a result, the paper can often be hard to read, lack flow, and omit critical components (which is not a good thing, especially if a grade is involved!).

The proper executing of *Argument Summaries* and *Checklists* will not only help you to organize your workflow when writing scientific papers, but they will (a) make it easier for you to construct a logical and convincing argument, (b) reduce your time spent on writing the actual papers, and (c) improve your grades.

3.2.1 Crafting a good argument

There are a number of different types of arguments made by scientists and the conventions that have been adopted for those modes of communication are directly related to the goal of the argument. We'll discuss two main types of arguments: (1) dissemination of results and (2) solicitation of funds.

In order to make a persuasive argument about the importance and validity of their results, scientists tend to write peer-reviewed papers in the past tense (mostly) and passive voice - which gives the illusion that the scientist does not affect the results - and they refrain (for the most part) from using the first/second person (we, I). Grant proposals, on the other hand, have a completely different purpose. They are not meant to disseminate results; rather, they are for the purpose of having a granting agency trust **us** (not just anyone) with money to do some (meaningful and useful) research. As a result, grants are generally written in the present and future tenses, and use the active voice. Often it can be the case that the even the best arguments can suffer because of lack of understanding of the conventions of how to best make them.

For now, we'll discuss the general framework for arguments being made when disseminating results - in the journal article. We'll return to writing grant proposals later.

3.2.2 Framework of the typical journal article argument

The four main sections of a journal article (Introduction, Experimental, Results and Discussion, and Conclusion) are not separate and disjointed pieces. Properly done, a good journal article tells the story of a scientific inquiry from inception to conclusion. Each section adds a new, different dimension to the experiment and helps to reinforce the overall argument that the author hopes to make with the paper.

Consider (a brief description of) the components that are found in each of the sections:

1. *Introduction:* the Introduction section of a journal article is where the author provides the foundation for the experiment. (a) Introducing the research area: what is the topic? Why is it important? Why should the reader care about the field/topic that you studied? This is the *Motivation* that we discussed in Assignment #1. (b) Identifying the gap: what exactly did you study? Why? This is the *Objective* of the experiment. (c) Summary of the literature/background pertinent to the study.

2. *Experimental:* what you did in explicit detail - enough that someone reading the paper should be able to reproduce the work, but without being overly verbose or including unnecessary details. When reading the Experimental, the reader learns the methods that were used in performing the experiment. Demonstrating the validity and rigor of the methodology is a necessary prerequisite to convincing the reader that the results have meaning. Note: the intended audience will play a large role in determining the amount, and types, of details that are necessary for an Experimental.

3. *Results and Discussion:* what was found and what it means. This section is, without a doubt, the most important section of the paper (which is why we will be focusing on it first). This section includes all of the important exhibits (tables, figures, values), an interpretation of these exhibits in the context of the background science, and an argument based on the results (what do the results mean? why are they important? how does this change things? etc...).

4. *Conclusion:* This section includes an extremely concise summary of what was accomplished in the experiment/study, in the context of the objectives. Additionally, the author makes claims about the relative successes/failures of the work, suggests possible future work, and – most importantly – explains the broader impacts that the results will have on the field and society.

Written in a cogent way, these sections come together to form a strong and persuasive scientific argument. That argument can usually be summarized in the following way:

- This is an important area of science (Motivation) and no one has done it yet (Gap; Objective), so we're going to do it in the following way — (in the Introduction)
- This is how it was done, so you know the results are rigorous! — (in the Experimental)
- These results indicate 'X'; 'X' means 'Y,' and is validated by 'Z.' — (in the Results and Discussion)
- As a result of 'X' and 'Y', we should do 'A' and 'B'; the impact on the world is 'C' — (in the Conclusion)

We'll use *Argument Summaries* as a way to start thinking about and organizing the papers that we will write.

> <u>Writing Sample 3.1: Argument Summary</u>
>
> Consider the following (silly and unrealistic) *argument summary* for an experiment to determine the %w/w sucrose in a sugar beverage:
>
> Childhood obesity is on the rise and soda is a significant cause (Motivation). Nevertheless, inexpensive methods for measurement of sugar content in food samples do not exist (Gap). To that end, a novel, pigmometric method for determination of sugar density in beverages is presented in this work (Experimental). Our method was benchmarked against a known soda solution, which gave results consistent with more expensive spectroscopy methods (5.1% relative difference). The new method was used to test an array of sodas for which the average concentration of sucrose was $15._1 \pm 2._1$%w/w, which is much larger than is safe for large-scale consumption (Results and Discussion). As a result ... (Conclusion).

3.2.3 Details relating to the effectiveness of an argument

The actual results of an experiment will dictate how strong the argument can be – after all, if the experiment fails there is no way (or at least there shouldn't be a way) to make a convincing argument that the results are meaningful. That said, there are a number of other factors that can help to a make a strong case for the results. Similarly, failing to take care in some of these areas can detract from the persuasiveness of even the most excellent results.

Choice of language

It is really important that you use terms properly. Words like *substantial* and *significant*, *related* and *correlated*, all have **very well-defined** meanings in the scientific world and it is important that you use the correct terms. Later chapters will address language choice in greater detail.

Many students, especially those new to the sciences, confuse the difficulty of a subject-matter with the complexity in the writing; these students tend to use overly complicated words and language, such as efficacious and utilize, instead of more appropriate words like effective and use. Equally problematic is the use of flowery and exaggerated language. Remember, the purpose of a peer-reviewed paper (Journal Article) is to communicate new findings, discoveries, and theories to the greater scientific public; to that end, always make sure to be as clear and concise as possible in your scientific writing.

Level of detail

Don't confuse brevity, simplicity, and concision, for lack of detail – in other words: don't be vague. Make sure that your arguments are specific and that you use enough detail to make your point.

That said, you also have to know your audience. It would be completely inappropriate to spend any time in your paper trying to convince your reader that burettes are precise pieces of glassware; if they don't at least know that, then they have no business reading your paper. Knowing where to strike the balance of brevity with sufficient detail is a hard thing to gauge - many career-scientists struggle with these same issues.

Make appropriate claims

Don't try to oversell your results. You aren't perfect, the methods you used weren't perfect, and there are intrinsic limitations in all scientific studies. Make sure that the claims you make are (a) supported by your data, (b) consistent with the limitations of your experiment, and (c) reasonable in relation to the literature.

Engage with the literature

A good argument is one that is based on **real scientific knowledge** gleaned from reliable sources. As a result, claims that are made must be accompanied by appropriate references to the scientific literature. Failure to cite the literature, in addition to being dishonest practice, results in a poor foundation and scaffolding for your argument.

Conventions of the discipline

Each section of the paper needs to conform to the conventions that have been established by the scientific discipline in question. Always make sure to consider the following details when writing your papers: (a) voice and tenses, (b) order and arrangement of the paper, (c) the proper use of tables and figures, and (d) other genre-specific restrictions.

3.3 Using a checklist to effectively outline a strong argument

When writing a paper, it is natural to develop a mental *checklist* of the things that we want to include. It has been our experience that explicitly writing down this checklist, before starting to write the paper, is one of the most instrumental steps towards ensuring that the paper is complete and well-organized. Moreover, using the checklist as a way to outline the argument that you want to make is the best way to ensure that your paper is cogent, well-organized, and able to properly convey the information that you want to present.

For the papers that we will write, that strongly mimic the journal article style, a checklist that starts with the components included in the Supporting Information, and continues section-by-section through the rest of the paper, is ideal.

3.3.1 Where does it belong?

Before preparing our checklist, we need to identify the data and exhibits that could/should be included in our paper. Determining the complete list of data and exhibits is trivial; conversely, determining the appropriate place to include an item in our paper can often times be very difficult. Consider the following:

- First, make sure that your *Supporting Information*[3] contains one *complete* copy of your data analysis. Your teaching assistant will be grading the technical merits of your analysis from your Supporting Information, so it is important that your analysis be complete with sample calculations, tables of relevant data, and the figures that you construct. While in the literature the supporting information comes at the end of a paper, we will have you put the supporting information at the *beginning* of your papers.

- Other than in the Supporting Information, sample calculations should not be found anywhere else in your papers. Additionally, raw data will not be include in your paper.

- The Results and Discussion section will contain a *subset* of the exhibits that your prepared during your analysis. The most important part of the *Results and Discussion* is the discussion of the chemical principles that underlie the results and the implications of these results.

- To that end, make sure that your Results and Discussion section only includes data that is **directly relevant** to the objective of the experiment – ask yourself: "does this information get across my message to my reader? or, does including this obfuscate the point that I need to make?". For a novice writer, this is possibly one of the most difficult parts of writing scientific papers. Often, students will choose to include substantially more than is appropriate. Not only does waste their time, but it also detracts from the strength of the paper. Work with your writing assistant (or teaching assistant) to try to get an appropriate balance – this is an essential, yet difficult, skill.

- The *Experimental* section will contain the absolutely necessary information that the reader would need to know in order to replicate the experiment (conditions, exact amounts). In synthetic papers, the yield (grams and %) are also reported at the very end of an Experimental subsection. In theory papers, or papers with a significant amount of non-standard treatment of data, the details of the analysis steps are given in the last subsection of the Experimental section (*Data Analysis*).

3.3.2 Choosing relevant data

It is rarely necessary to include all of the data that you collect in the lab in your Results section. In fact, most times the actual data that is collected falls into the category of *Raw Data*. Raw Data (also referred to as primary data) refers to any measurements that are collected in the lab that have not been subjected to processing or manipulation. For example: masses of weighing jars and solids, volumes on a burette, and initial and final temperatures, all fall in the category of raw data.

[3] In the 'real' science writing world, the Supporting Information contains everything that you (or, more importantly, your reader/instructor) find informative, but that does not have a home in any of the other sections. These are usually quite brief and only contain essential items that were not put in the full paper. Our supporting information sections will be much more expansive.

Once the data have been *processed* you will have to further distinguish between the data that are necessary to present in the body of the paper, and those which are not necessary. Extensive, but relevant, data should be included in the *Supporting Information*.

To illustrate, consider the product of a synthesis that was weighed by difference: the only 'Result' is the % yield. The raw masses are not relevant and should not be given. Additionally, if you performed ten replicate mass measurements then only report the mean (with associated confidence interval); it is unnecessary, and inappropriate, to report all ten measurements, the standard deviation, and the rest of the raw data in the Results section.

3.3.3 Preparing a checklist for your paper: a step-by-step guide

Especially when writing a paper in the sciences, there is a long process that precedes the writing of a paper or even a checklist. Novices who "jump" straight into writing their paper will usually end up wasting a tremendous amount of time and rewriting large sections, if not the entirety, of their paper.

Consider the following approach that *experts* use when writing their research papers:

1. *Data Analysis:* Whether the subject of your paper is Dante or chemistry, you need to know what you intend to write about before you start writing! Start by completely analyzing your data and preparing any relevant exhibits (figures and tables). Only once you've sorted out the results of your experiment can you begin to ponder what you intend to argue.

2. *Plan your argument and do your research:* These two tasks, planning an argument and doing research, are inextricable. Answer the "seven questions" (see above) to guide your research and your planning.

3. *Argument Summary:* Prepare an argument summary based on your answers to the seven questions and the research that you did to get your answers.

4. *Parse your data and prepare a checklist:* Expand your argument summary into a checklist of items that you intend to include in your paper (in an order that makes sense). Return to your data analysis and decide what data need to be included and what can be omitted.

3.4 Examining a checklist

Consider the sample checklist that is included at the end of the chapter. This checklist is one that might have been used for writing a paper reporting on an experiment to measure the sugar concentration of sodas by their densities (like the one that we started discussing in the Writing Sample above).

Notice several important features of the checklist below:

1. It is very *terse*! This is not the paper, or even the beginnings of the paper. Rather, it is a comprehensive checklist of all of the things that you would want to have in the final draft.

2. While *colloquial writing* isn't acceptable for writing scholarly papers (nor is the use of the first person), it is perfectly acceptable for your checklist to be colloquial.

3. Be very *specific*! Don't just write "motivation" or "reason for studying sugar"; rather, actually list the specific items that you intend to write about.

4. The *Supporting Information* is first! The first place to start when writing a paper is to **fully** work up the data.

5. Using something (like an asterisk *) to indicate the items that were the result of *your research* and, hence, need *citations* to the chemical literature.

The importance of checklists cannot be overemphasized – they are an indispensable tool for streamlining workflow and organizing the scientific content of papers. Traditionally, the grades on papers tend to be **much lower** when students do not produce checklists, or when inferior checklists are made.

3.5 End-of-chapter assignment

1. Consider the process of standardizing a solution of potassium permanganate: the mass of sodium oxalate is recorded by difference on a balance and the volume of the permanganate solution delivered is determined from the initial and final volumes on a burette. Reproduce the following table (make sure to follow proper Table conventions); for each item in the table, indicate the *type* of data (data, raw data, processed, or statistic) and the *location* where it would be presented in the paper (Experimental, Results/Discussion, Supporting Information, or nowhere).

Value / Data	**Type**	**Location in paper**
Mass of weighing jar		
Mass of weighing jar plus oxalate		
Mass of oxalate (by difference)		
Initial volume on burette		
Final volume on burette		
Total volume delivered		
[$KMnO_4$] from trial #1		
Average [$KMnO_4$]		
Standard deviation in [$KMnO_4$]		

2. Consider the most recent lab that was performed and go through the steps that you would take in preparing a checklist for a paper on this lab (though we will not actually write the paper):

   (a) After completing your data analysis, answer the “seven questions” to help you plan your argument (questions 3 and 4 will likely be difficult the first few times).

   (b) Propose an *Argument Summary* for the paper using the style used in the sample provided.

   (c) Tabulate the data and exhibits that you prepared in your analysis. Indicate where in the paper (or Supporting Information) these would be included.

   (d) Prepare a checklist, of the style described above, that you could use to write a strong paper based on your argument summary. Remember that your goal is to prepare a strong, and well-organized, argument. *Note*: you do not need to include an Experimental section in your checklist.

Sample Checklist

Experiment #42 Partner: W. Eirdo **Due date: 1/1/1900**

Supporting Information

- **Table** with masses, volumes, densities, and %w/w sugar of the standards.
- **Table** containing the masses and volumes of the soda samples used; densities of soda samples; and concentrations from standard curve
- Sample calculations for (a) the densities from mass and volume and (b) the statistics for multiple trials.

Introduction

- Sodas are a very common beverage in US homes (*), but have health risks: obesity (*), diabetes (*), and ??? (*)
- Easy method of determining sugar concentration in sodas using density
- Information about density of sucrose solutions (*), $d = m/v$

Experimental

- Materials and methods: source of chemicals, analytical balance used, volumes recorded in volumetric flasks. *Is this necessary??* (No)
- Preparation of the standard sucrose solutions
- Measuring the densities of the standard solutions and sodas

Results and Discussion

- **Figure**: Standard curve for %w/w sucrose vs. density
- Discussion of linearity/trend in the curve; R^2 is close to 1, it's so linear!
- **Table** for soda unknowns: average ($\pm s$) density, average ($\pm s$) %w/w sugar, %error from known value
- Compare the sodas:
  - Which has the most %sugar? the least?
  - Statistical comparison to known/manufacturers values (*for each)
- Largest uncertainty in method is the other components in the soda - do they contribute to the density(?) - Yes.

Conclusion

- Experiment successfully used density to determine %sugar that matched manufacturer's claims.
- Improvement: next time I'll ...
- Broader impact: the sodas to stay away from are ...

4

Writing an Abridged Report

4.1 What to avoid in scientific writing

Having discussed the general type of writing that we will be doing, polished our use of Tables and Figures, and outlined our paper with an argument summary and a checklist, we are now ready to begin writing our report (in the Journal Article style). Before you begin writing, first consider the following general guidelines about what to avoid when writing scientific papers:

1. Avoid colloquialisms: it is very tempting to write the same way we speak. Colloquialisms can be broken down into a few categories:

1. *Inappropriate words* such as gonna, y'all, or ain't;
2. *Phrases* like "since the dawn of time" or "as blind as a bat;"
3. *Aphorisms*, iconic sayings, like "There's more than one way to skin a cat;" and
4. *Profanity.*

2. Be specific, never vague, and avoid using overly grandiose statements. It is important to be very specific in scientific writing. Words such as numerous, incredibly, enumerable, and essential, are usually inappropriate.

3. Using overly complicated words and phrases. Students new to science, and science writing, almost always make the same mistake: they use overly complex terms/words (*e.g.* efficacious vs. effective; proximal vs. close). When new students start reading the scientific literature, or even just science textbooks, they find themselves challenged by the depth and difficulty of the concepts being presented. It is very easy to mistake the difficulty of the science with complexity in the writing. In reality, scientists strive to write their complicated concepts in the most concise, precise, and simple language possible.

4. Avoid "Lab Speak." In general, lab speak refers to language that identifies the writing as being for a course in college, rather than a body of scientific information. Examples of inappropriate language include: in the lab, in this experiment, the student, and in the procedure. In many cases, the offending clause can be omitted, or in some cases replaced with more appropriate versions such as 'in the present work.'

> Example 4.1: Overly General Statements
>
> *Incorrect:* "Potassium Aluminum Sulfate (Alum) is an incredibly useful inorganic white crystalline compound possessing numerous purposes both in regards to ecological sustainability and also everyday usage."
>
> *Correct:* "Potassium aluminum sulfate (Alum) has uses in water purification[1], paper sizing[2], leather tanning[3], mordant dyeing[4], synthesizing baking powder and antiperspirants[5], and usage as a medical astringent.[6]"
>
> Notice that the first version is extremely vague. The second version enumerates the uses of Alum, instead of making unfounded, grandiose claims. Also, each claim in the second version is supported by an appropriate reference to the literature.

5. Refrain from using anecdotal statements. It is not uncommon for students who are new to scientific writing to make statements that begin with "it is well known that" or "most people know." When writing for a scientific audience, however, these types of statements are inappropriate. Consider the following: if they are so well known, then you need not say them at all. If, however, they are important enough to say, then you should make sure to support your claim/statement with appropriate references.

> Example 4.2: Anecdotal and general statements
>
> *Incorrect:* "Despite this lack of confidence, the consumption of vitamin supplements is very widespread."
>
> *Correct:* "Recent data[1] indicates that 90% of the population consumes a vitamin supplement regularly."
>
> The first statement is extremely vague and is not supported by any sources. The corrected version gives the same information (that most people consume vitamin supplements), but is also very specific and is supported by a reference.

6. Avoid repetitive use of the same words or phrases. The best way to make sure that you are not repeating the same word, or clause, too many times is to re-read your paper before submitting.

7. Run-on sentences are somewhat difficult to avoid while we are striving to be concise in our writing. That said, a quick re-read through your paper should help you to identify sentences that are too long and complex. Similarly, if you have two or three short sentences about a single point, try to combine them into a single, well-written, sentence.

8. Never use direct quotes. Don't cite for the sake of citing and never use direct quotes. Your citations are for information that you used from other sources and are brought to support your assertions and your argument.

Example 4.3: Repetitive clauses

Incorrect: "The volume of acid added to reach the point where a monolayer forms could be *more accurately determined* by using a device such as a microscope to *more accurately determine* exactly when the monolayer has formed."

Correct: "The use of microscopy could help to more accurately determine the point at which the monolayer had formed."

Unnecessary repetition was removed from the first version.

4.2 Best practices in scientific writing

Knowing what to avoid is only half of the battle - it is more important to know what to focus on when writing your paper. Consider the following general guidelines about how best to approach writing a scientific paper:

1. Focus on argument: while it can be tempting to think about writing a lab report as a means to a grade, it is important to make a strong argument: focus on telling a convincing story about science. Always start by writing an *Argument Summary* for your paper (see #3).

2. Less is more, especially when it comes to data. Flooding your reader with a ton of data, figures, and tables, can only lead to one thing: confusion. Only show the data that *needs* to be shown, and do it in the most appropriate way (Table, Figure, or prose). Before you move on with your writing, start by making a list of the data that you have and make a plan for how you will (or won't) present it.

3. Don't forget to make a checklist. I've heard some rhetoric instructors suggest that someone 'just start writing and it will come to you.' This may work for some, especially in the humanities, but it is a terrible idea in science. Starting by sketching out your paper in a checklist means that you are more likely to make a convincing argument that follows a logical flow.

4. Have a good flow. Don't write like you are checking boxes off a list (even though you are checking off from your checklist). It can be easy to start each new component with a broad and general declarative statement like 'The results show ...', 'In conclusion we believe ...', and 'The sources of error are ...'. Instead, try to make sure that your paper has a natural and smooth flow. Just talk about your results and the associated uncertainties, without unnecessarily calling attention to each component by name.

5. Proofread your work to make sure that you've written a concise and convincing paper. It is best to let some time pass from the initial writing before you proofread - usually the next day works best. Also, let a friend read it – and not someone in the course. Your job is to be a teacher and presenter; did they understand your argument?

6. Most importantly: less is more. This cannot be overemphasized: length has no correlation with quality (though it can have an inverse relationship at times). Graders are not fooled by overly verbose, unnecessarily long papers. Rather, they are looking for a well-reasoned, scientifically correct, and concise argument. Give them what they want!

Example 4.4: Good flow

Incorrect: "The result of the manganometric determination of the % V composition is that there is $45._5 \pm 6._6$% vanadium in the complex. The theoretical value for the % V is 40%(*). The experimental value is statistically consistent with the theoretical value. The relative standard deviation is 14.5%. The possible source of error that led to the large relative uncertainty is like the presence of bisulfite contamination."

Correct: "Managanometric titrations of compound **1** suggest a $45._5 \pm 6._6$% vanadium composition, which is consistent with the predicted formula of $(NH_4)_6V_{10}O_{28} \cdot 6H_2O$(*). The relatively large deviation from the theoretical value (12.5%), as well as the 14.5% uncertainty, are expected with mangamometric titrations of solutions containing small amounts of bisulfite."

The second version relates the exact same information, but does so in a concise manner that flows nicely.

4.3 Results and Discussion Section

The Results section and the Discussion section is probably the most important section in a lab report:[1] this is where you will first present your results and then explain the results in the context of the greater objective. In the Results section, you should present your data and any pertinent figures.[2] Following this, you will explain your results (i.e. Discussion) to assert your relative success or failure in relation to each of your stated goals. This is the climax of your story — it is crucial that you be clear, persuasive, and complete.

While it can sometimes be tempting to flood the reader with tons of data, tables, and figures, the most important thing to remember is that *the Results and Discussion must be clear and readable.* The quality of the science is irrelevant if the reader cannot glean the relevant information. The Introduction and Experimental sections are like the beginning of a nice story. Don't mess up the climax of your story (Results and Discussion) by having an incomprehensible section.

4.3.1 Content and Organization

The Results section will include all data relevant to the objective of the lab performed and discuss each result after it is presented. For example, the results of a titration of an unknown analyte will include the relevant information that you were measuring. For other experiments, you will report information like yield, spectral data, and crystal data, provided that these have not already been included in the Experimental section. Large amounts of numerical data are often best presented in tables or figures (but rarely both for the same results). For detailed instruction about where different data belongs, see Assignment #3.

Given that most of the experiments you will perform in a four or eight hour lab session are of limited scope and length, the amount of Results that you have will tend to be minimal. The most important

[1] For the record, this could probably be said about all of the sections.
[2] Proper formatting and use of figures was discussed in a previous assignment.

part of the Discussion is to state whether or not the results of the lab support your original hypothesis (or whether the original objective was met). If the hypothesis was partially supported, or supported with exceptions, this should also be explained.

In all parts of the Discussion it is important to explain how the specific data led you to your judgment about your hypothesis. Use your understanding of the scientific concept of the lab to explain your judgment. Whatever the relationship between the hypothesis and the results, you must provide a logical, scientific basis for it. If your results do not support your hypothesis, then explain why not. Supporting your assertions will involve, where relevant, the following Discussions for each individual result:

1. *The science:* this is the most important part of the discussion - the science behind what happened and why it happened. This can be the trickiest part, but it is the most crucial part as well.

2. *Accuracy:* How accurate is your result? This question is answered by qualitatively and quantitatively (one sample t-test, % relative error) comparing the result to a known (literature, standard, and manufacturer's) value. Remember: references must be supplied for all literature values.

3. *Precision:* How precise is your result? Discuss sources of imprecision and how they affected your experimental outcome.

4. *Statistical:* If you have collected enough data, it is appropriate to make a statistical comparison of your result to the literature value. Don't forget to make a bottom-line assertion of whether or not your result is consistent with the known value.

5. *Uncertainty:* Discuss the **major source(s)** of error and how it affected the accuracy and precision of your result. This should be done as your are reporting your results, and not at the end of the section. Also, remember that your stated error(s) should support the outcome of the experiment: this means that you should not claim that product was lost as a source of error, if your percent yield was greater than 100%!. Don't blame your teaching assistant, lab partner, or "human error." What you should represent as the error should be based on how the *method* was not sufficient in producing good results. Finally, don't list-off possible sources of error. Be specific and list the most probable, and considerable, sources and explain how they relate to your results.

Additionally, if you have multiple results that are related, it is appropriate to compare those results (statistically, when possible). An example of this is if you were measuring the same value using two types of experiments. Other significant, more global, sources of error should also be discussed.

A good Results and Discussion

Remember, a good Results and Discussion section will focus on the science behind the experiment, in the context of the argument that we are trying to make. Don't focus on error, accuracy, and precision (though you do need to include this information and discuss it); rather, use this section to explain what happened. Where relevant, use the 'Questions for Thought' to help guide you in preparing your discussion. Consider answering questions like 'what does it mean' or 'how did it work/happened?'

Avoid writing in a manner that seems like you are checking things off a list. Use your knowledge of how to frame a strong argument to prepare a well-reasoned section.

All of that having been said, this is not the section for gross generalizations about the overall success or failure of the experiment. Those types of statements and discussions are left for the Conclusion section (Assignment #6).

Dealing with 'bad' data

One of the hardest things for students to do is to resist the compulsion to rationalize, or ignore, 'bad' data. The results that you obtain in any given experiment are, for better or for worse, what you have to work with. Moreover, your instructors know whether the result is actually *consistent*, *acceptable*, or *reasonable*. Please refrain from claiming that 250% error is anything other than what it is: a bad result. You will not lose credit in your analysis[3] for stating the objective facts about your results; on the contrary, you will only be awarded full credit for a discussion that properly, and objectively, matches your results.

That said, it is also equally important to write with certainty and clarity. Avoid vague and unconvincing language, such "maybe" or "it could be," and be assertive in your claims.

4.3.2 Format and Style

The Results and Discussion section will consist of paragraphs and may, when relevant, include tables and figures. A Results and Discussion section that consists uniquely of tables and figures is **not acceptable**. Ideally, a person reading your paper should be able to at least extract the bottom line without ever looking at a table or graph.

While there is no specific page limit for this section, it is best to keep the Results as brief as possible. If your experiment contains multiple (more than 2) central results, then you may find it useful to break your Results and Discussion into smaller subsections. Each subsection should start with a heading (i.e. *Spectral Data* or *Stability Results*) - do not use "Part .." in your headings.

The Discussion consists almost entirely of prose that is written in the past tense and passive voice. While the Discussion should be persuasive (*anyone* would come to the same conclusions based on your data), it must also be objective. Relevant chemical equations, tables, and figures are also included where they are needed to explain each Result. Sample calculations never appear in the Results and Discussion (they should be shown in your Supporting Information section, which appears after the References; never reference your Supporting Information).

The hardest part of writing a successful discussion is to make sure that you've included all of the key components (see the *Contents* section) without sounding like you are crossing requirements off a list. Simply listing values will not make for a persuasive Results and Discussion. It is important that the transitions between paragraphs be smooth, not abrupt. You should make sure to introduce what you are about to present so that the reader understands the flow of the argument.

4.3.3 Tables, Figures, and Equations

There is likely to be a considerable number of tables, figures, and equations in the Results and Discussion section. It is critical that all of the aforementioned be properly formatted, numbered, and referenced in the text. See Assignment #2 for further details.

4.3.4 Voice and Tenses

Chemistry papers are almost always written in the passive voice and the past tense - this gives the impression that the results of the experiment are not dependent on the person actually performing the work, but that they would be the same if anyone would do the experiment. The Results and Discussion section will contain both the past and present tenses, where appropriate. The work done *in the past* should be described in the past tense ("the structure was determined by ..."), while the truths that are gleaned

[3] That is not to say that you won't necessarily lose credit for your results, but those points were forfeit no matter what you would write.

from the research are in the present tense ("the structure indicates that ..."). Additional grammatical concerns include:

- Sentences should never begin with a numeral (0 - 9). Therefore, write "two" instead of "2"[4]. If you are reporting an amount, consider something like: "A 5.00 g sample of ..."
- Always put a zero before a decimal point (0.1, not .1).
- Use words to write out numbers for non-measured numbers less than 10.

4.3.5 Common Mistakes

- Students often present chemicals and values improperly.

> Example 4.5: Formatting of chemicals
>
> *Incorrect:* "The mass C2H4 was found to be 3x10ˆ-3 g."
>
> *Correct:* "The mass of C_2H_4 was found to be 3×10^{-3} g."
>
> In the first statement, both the format of the ethene and the value are unacceptable. They are correct in the second example.

- It is important to remember to refer to Tables and Figures in the paragraphs.
- Students often present too much data: discussing too much in a single paragraph, overuse of Tables and Figures, presenting too much raw data, presenting the same data in multiple places (it is unnecessary to present every datum from a table in the text).

> Example 4.6: Raw data
>
> *Incorrect:* "The density of the products were recorded and found to be 1.2 g/mL, 1.1 g/mL, 1.2 g/mL, 1.0 g/mL, 0.9 g/mL, 1.3 g/mL, 1.4 g/mL, 1.2 g/mL, 1.3 g/mL, 1.2 g/mL. The average was found to be 1.2_1 g/mL and the 95% confidence interval was $1.2_1 \pm 0.1_1$ g/mL."
>
> *Correct:* "The average density of the product (10 replicate measurements) was determined to be $1.2_1 \pm 0.1_1$ g/mL."
>
> For all of the reasons mentioned previously, the second statement is far superior to the first statement. In the *Data Analysis* section you would report that all confidence intervals were computed at the 95% confidence limit.

- Make sure to relate the error to the result. For example: losing product during filtration is not a good source of uncertainty when the experimental value is larger than expected. (Remember: TF's and lab partners are not sources of uncertainty/error!)

[4] Proper grammar dictates that numbers less than ten (10) be written as words rather than numbers. This does not apply to measurements.

- Forgetting to provide a reference for a literature value(s). Additionally, always support assertions, where possible, with citations to the literature.
- **Never** reference your supporting information. If it is critical information then it needs to be presented in your paper. Otherwise, it is incorrect to refer to it.
- Using an informal tone (voice other than past tense, passive, and third person). In an effort to be persuasive you may be tempted to flirt with the first or second person: do not. It is more important that the Discussion remain objective.
- Being overly verbose. While it is important that the Results and Discussion 'flow', it is important to keep it relatively short and to the point.
- Summarizing the lab. A summary of the relative success or failure, in brief, is made in the Conclusion section. The Discussion section should involve details rather than vague generalizations. That said, it is important to make sure that you state whether or not your results support your original hypothesis.

4.4 Conclusion Section

The conclusion ties together the entire experiment. To this end, you should not simply duplicate statements made in the Discussion, rather you should present a **brief** overview of the whole study, with a summary of the main findings, and conclusions of the study, particularly the larger ramifications.

4.4.1 Content and Organization

There are three major components of the Conclusion section:

1. *Summary:* Briefly summarize the main conclusions of the lab, including a brief restatement of the objective/goal of the lab. Were the lab's objectives achieved? If so, to what degree? If not, how unsuccessful was the experiment?

2. *Future Developments:* Suggest, and where appropriate explain, any future development/work that could be made to improve the accuracy, precision, ease of performance, or overall outcome of the experiment. In other words, what modification(s) would you make if you were to perform the lab again (be constructive[5])? Hint: consider the major sources of error that you mentioned in the Discussion - these are great places to start. These suggestions need not be grandiose (actually, better solutions are simple ones that are easy to implement), but they should have a relatively large potential for impact and be consistent with the results of the experiment. Alternately, or in addition, this is the place to think about future research that could be done based on the results or the methodology.

3. *Global ramifications:* Overall, what was accomplished? What did you learn[6]? How does this change the world?

   It is very possible, especially if the experiment was not successful[7] (or had limited success), that there are no global ramifications to the work. In this case, focus more on suggesting methods of improvement.

[5] It is important that the suggestions for improvement be relevant, possible, and intelligent.

[6] What you learned does not refer to the academic mission of the lab (titrations, UV/Vis, AAS, etc...). This is referring to what was learned from the experiment (the amount of Iron in cereal, etc...).

[7] Whether, or not, your lab was successful, you need to fulfill this requirement in your report.

4.4.2 Format and Style

Voice and Tense

Unlike the previous sections that were written entirely in the past tense, passive voice, and third person, the Conclusion discusses the present and the future. This fact can make the writing of the Conclusion technically difficult. Keep the following in mind:

- *Summary:* The summary is about data that was collected in the *past*. This component should be written in the past tense and passive voice (like the rest of the lab report).

- *Future development:* This component is referring to work that may, or may not, be done in the *future*. Additionally, since it is yet to be determined whether or not someone will actually make those improvements, it is not appropriate to use the *Indicative Mood*. Rather, the author should write these statements either in the *Conditional Mood* or the *Subjunctive Mood*. The Conditional mood is marked by the use of the words *might, could,* and *would*. The Subjunctive is a little more tricky and, frankly, dated way of writing. The Subjunctive mood is characterized by statements like "*if ... were*", "*I wish that*", "*I desire that*", "*I* **suggest** *that*". In either case (Conditional or Subjunctive), the goal is to make it clear that these are suggestions that may never actually come to fruition. This portion is still written in the third person.

- *Global ramifications:* These statements will either speak about how the study will impact the future of the field or how they have changed the current state-of-the-art. These statements should be written in the *future indicative* and *present indicative*, respectively.

Normally, the bulk (all) of a scientific paper is written in the third person and passive voice. This is done to give the impression of objectivity - that the results, and conclusions that are drawn from them, would be achieved had anyone done the experiment. In the conclusion and sometimes in the Discussion, however, including a single statement in the first person plural (we) is an elegant way of reaching the reader on a personal level. Most often, these types of statements are best used to convey how you believe this experiment is profound and will impact science. Your Conclusion section should include one such statement, but be careful that it not be when restating the Results - these should remain objective (third person).

Length and Depth

The Conclusion is the shortest part of the lab report. In general, a Conclusion will be a single paragraph (sometimes two), that should not significantly exceed half of a double-spaced page.

4.4.3 Common Mistakes

- Some students will tend to go overboard now that they've been given license to add a touch of personalism. Make sure that the Conclusion still reads like part of a scientific paper and not a personal journal/notebook.

- Having read the previous line, students can be timid to implement a personal touch to the Conclusion. This is equally problematic. A good Conclusion will draw the reader in to the work and have them finish with a good sense of conviction about the work.

> Example Conclusion(2)
>
> *Incorrect:* "We believe that our results were accurate."
>
> *Incorrect:* "We believe that this work will change the world!"
>
> While the first statement may be correct, it does not leave the reader with a strong feeling about the work. That said, the second statement is more appropriate but is way too broad!

- Suggestions for improvement should be possible. Also, since it is not clear that the experiment would ever be repeated, future development should be discussed in a passive voice (suggestion), rather than a definite statement about the future.

> Example Conclusion (1)
>
> *Incorrect:* "Completely abandoning the field and reinventing the wheel will lead to better precision."
>
> *Correct:* "Ensuring consistency in the sampling method could lead to lower relative deviation."
>
> The first statement, which may sometimes be true, does not give any real constructive suggestion on how to improve the experiment. Additionally, the first statement is written in a manner that leads the reader to believe that the author will definitely implement their future development work.

4.5 Overall Considerations for Abridged Reports

There is a lot to consider when approaching your Abridged Report. Consider the following:

- Start with a good *Argument Summary* (see chapter #3) for your paper. Use this argument summary when planning your checklist.
- A good checklist for your paper - submitted along with your paper - is required in order to receive full credit;
- Focus on developing a **concise** paper that has a good flow and a **strong argument**;
- Make sure to following the guidelines about what to avoid in scientific writing;
- After completeness, focus on the correct use of voice and tense. To achieve a paper with a strong argument you will need to write in the proper tenses;
- Don't forget to look for important minutia, such as referring to tables and figures (by number) in the text;
- Make sure your Tables, Figures, and Equations, are all properly formatted; and

- Always remember to look over your work with a critical eye for the 'common mistakes.' They are so named because they are very common!

4.6 End-of-chapter assignment

1. Use the information in section 4.1 to critically analyze each of the following excerpts from actual lab reports. For each, indicate what general guidelines have been ignored / violated, and propose a version that is more correct (it is possible that more than one thing is wrong with each). Note: where you feel that a reference is merited, simply indicate with a superscript. There is no need to actually look up references for this assignment.

   (a) The experiment is designed to introduce the student to the industrial chemistry process, and give an idea of how the basics work.

   (b) While this objective was trivialized with the use of a spectrophotometer, the information gained from acquiring the absorbance of the dyes is the true matter being put to investigation. By putting the dyes through a spectrophotometer, the absorbance and wavelength of the dye was established. Why was knowing this important? The true objective of this lab was to test the particle-in-a-box model, and test it for its accuracy in predicting the wavelength of light emitted from the dyes.

   (c) With the accuracy of determining Avogadro's number hinging upon multiple factors, it is to no wonder that advanced researchers have shifted away from measuring N_A in such error-ridden experiments and towards more exact methods such as X-ray crystallography.

   (d) Any other error was either systematic or human, and would account for faulty data and inconclusive results.

   (e) The relative standard deviation was also 5.45% showing that the lab was executed with some precision as well.

2. After completing your data analysis, answer the "seven questions" (see chapter #3) to help you plan your argument.

3. Propose an *Argument Summary* for your paper; tabulate the data and exhibits that you prepared in your analysis and indicate where in the paper (or Supporting Information) these would be included; and prepare a checklist that you will use to write your Abridged report (you do not need to include Introduction and Experimental sections).

4. Based on your argument summary and table of data, use the information in this handout (and all of the previous handouts) to write an Abridged Report (Results and Discussion, Conclusion, References, and Supporting Information) for your most recent lab (make sure to include your argument summary and checklist).

5

Exploring the literature to develop an argument

5.1 Questions, Answers, and Search-engines

6

Writing Like a Chemist

6.1 Good practices in scientific writing

The major goal of scientific writing is the communication of information in a clear, concise, and unambiguous manner. While journal articles must of course follow general grammar rules, which apply to all written work, there are conventions, accepted practices, and methods which specifically apply to, and benefit, scientific writing. The Experimental section often suffers the most when the good scientific writing practices are not implemented, so many of the examples will be in the context of that information.

6.1.1 Concise Writing

The nature of the scientific process (multiple trials, incremental modifications, comparison of similar data sets, etc...) makes it easy to fall into the trap of repetitive writing. The complicated, multi-step techniques or analyses can also lead to tendency for verbose descriptions. Finding a balance between clarity and brevity can be difficult, and you must therefore carefully consider the information you are trying to convey to the reader, as well as the audience to whom you are writing.

It may help to keep some questions to yourself in mind while writing:

1. *"Would the level of scientist who was interested in reading/replicating this work need me to explain the details of this step, or just the fact that it was done?"*: Many techniques you will employ in the chemistry are routine or commonly practiced, and would therefore be familiar to the reader. While it is difficult at first to make the distinction (since most of these techniques are fairly new to you), this ability will develop over time as you are exposed to more types of experiments and have a chance to see which methods appear over and over again. (See Example 6.1)

2. *"Was the same exact technique used on all samples?"* or even *"Was there only that one systematic difference implemented among the trials?"*: If a method was used in the same way across multiple trials, a single explicit description using one representative set of numbers is sufficient with the rest summarized as replications. For cases with just one small difference or a series of systematic differences, these can also be summarized with a single concise sentence. (See Example 6.2).

3. *"Does having these data points all written out in long sentences really make my point or is there a better way to represent it?"*: Having multiple sentences with lots of numbers, or many sentences

outlining multiple differences (*e.g.* solution preparation) is confusing and can contribute to your point being lost. These cases are better served by a table (or occasionally a figure).

Example 6.1: Process Details

Incorrect: "The powder of sodium sulfate (Na_2SO_4) was placed in the 200 mL volumetric flask and then DI water was added to about halfway, creating a dark blue solution. The mixture was then swirled around with the water to ensure good mixing. More DI water was then slowly added until the edges of the meniscus came up to the mark. The solution was then capped and mixed by inverting the flask five times. This resulted in a final solution that was lighter blue. The final concentration was $0.0081M$."

Correct: "A 200.00 mL sample of $0.0081M$ Na_2SO_4 was prepared, resulting in a uniform and clear, light blue solution."

The first version reads like a lab manual written in the past tense. The second isolates the useful information in a clear and concise manner. Note: the use of proper significant figures implies the use of volumetric glassware (this may also have been specified in the Materials and Methods section). Also, steps such as thorough mixing are assumed as they are fundamental practice.

Example 6.2: Repetition

Incorrect: "*Preparation of solution A.* Unknown tablet A (1.0561 g) was crushed and dissolved in 50.00 mL of DI water with continuous swirling over heat. A 5.00 mL aliquot of this solution was then transferred to a beaker and 5.00 mL of $0.1M$ $HNO_3(aq)$ was added. ...

Preparation of solution B. Then unknown tablet B (1.1201 g) was crushed and dissolved in 50.00 mL of DI water with continuous swirling over heat. A 5.00 mL aliquot of this solution was also transferred to a beaker and 5.00 mL of $0.1M$ $HNO_3(aq)$ was added. ..."

Correct: "*Preparation of unknowns.* Unknown tablet A (1.0561 g) was crushed and dissolved in 50.00 mL of DI water with continuous swirling over heat. A 5.00 mL aliquot of this solution was then transferred to a beaker and 5.00 mL of $0.1M$ $HNO_3(aq)$ was added.... This process was repeated for tablet B (1.1201 g)."

In the first example, the nearly identical procedure was described twice (though the mere act of separating them is already an improvement over an Experimental written in one, long section). In the second example, the two preparations are combined and it is explained that the procedure was merely repeated for a second unknown, with the only difference being the mass of the tablet.

6.1.2 Table, Figure, or Prose?

Well-formatted tables and figures can be a valuable space saving tool in scientific writing. Not only can they concisely represent related information, they can also be a more clear and easily understood way to showcase data. Since a maximum of 5 of 6 ideas can be kept in conscious thought at any time, tables and figures are a good way of organizing and presenting complicated data. Trying to read a long series of numbers in a sentence can fatigue or confuse a reader, causing the relationship you are trying to showcase to remain hidden. Numbers that are cleanly aligned with well-defined column headers (with units!) allow those relationships to be easily discerned or emphasized.

The primary difference between tables and figures is regarding the necessity of the reader to know the precise values of the data. For instance: in a chromatogram or spectrum (where a figure is **always** preferable to a table), the multitude of individual points are usually irrelevant; rather, if is the trend or shape that is of importance. Of course, the maximum values or integrations would be discussed in the prose that immediately precedes or follows the figure.

Although the minimum requirements for a table (see previous assignment on tables and figures) are a good start, deciding when a table is truly beneficial can be tricky and is often best decided by trying it out: simply make a table and see if you can organize it so that it depicts the information more clearly. Sometimes the benefits are clear and sometimes the table wastes more space than its worth. Never use a table that has a single column or row of data.

Referring to data in tables and figures

Now that you have made a decision about what data belongs in a table, you will have to work a reference to that table (by number) into the text of the relevant section - if you do not need to reference the table or figure, then it is irrelevant and can be omitted. You do not want to undo all the space saving efforts of using a table by restating the majority of the data as prose.

That said, a reader should be able to obtain all the most relevant information about your work without looking at any figures or tables. Usually, the text will speak more to maximum and minimum values, trends, and implications of the tabulated data.

6.1.3 Proofread

Though it should go without saying, you absolutely must proofread your work to make sure that you've produced a concise, well-written paper that conveys a convincing argument. Consider writing your paper early and allowing some time pass from the initial writing before you proofread - usually the next day works best. Also, it can be **very** helpful to let a friend read it – and not someone in the course. Your job is to be a teacher and presenter; did they understand your argument?

6.1.4 Less is more

The length of your paper has no correlation with the quality of the paper. On the contrary, overly verbose rhetoric is unacceptable in scientific writing.

6.2 Common grammar mistakes in (scientific) writing

Many people fall into the habit of writing as they speak. While this may be suitable for some literary styles, it can often cause ambiguity in something meant to be read as technical writing. Some of the most common mistakes seen from introductory (chemistry) students include poor choice of words or phrases, wordiness, confusing word order, and poorly constructed modifiers.

Of course, keeping these things in mind when starting to write will help, but the easiest way to catch the ones that slip through is to RE-READ YOUR WRITING! Preferably, you should not be reviewing just as you have written it, but rather after a break where you have distanced yourself from the content - re-reading immediately is significantly less effective because often the context of what you were writing remains fresh in your mind and it is difficult to adequately judge the writing (after all, you knew exactly what you wanted to say!).

6.2.1 Choice of words

Choosing the appropriate words is by no means a problem unique to science writing. Rather, many introductory writing instructors often complain about some of the more confused words found in student writings.

Below you will find a list of some of the most common mistakes in word choice amongst novice writers. This list is by no means exhaustive, but should serve as an primer to the types of grammatical errors that should be avoided.

- **Its** vs. **it's**: the often cited pet-peeve of writing instructors, these often confused words are relatively easy to disambiguate. *Its* is possessive, while *it's* is a contraction of 'it is' or 'it has' - if you can't replace it with one of these, then you are likely trying to use the wrong one.
- **Their** vs. **they're** vs. **there**: *Their* is possessive (their piano is red). *There* is a place or an idea (there were small amounts of white crystals that formed). *They're* is a contraction of 'they are.'
- **Ensure** vs. **insure**: To *ensure* is to make certain that something occurs, while to *insure* is to arrange for financial compensation in the event of loss or damage.
- **Then** vs. **than**: *Then* is used to denote time, while *than* is used for comparison.

Proper word usage is of particular importance to scientific writing, because of the many possibilities for confusion in meaning resulting from simple word choices. Many words have connotations or implied meanings when used informally, but take on specific meanings in a scientific setting. This can be a result of adopted colloquialisms and/or the use of gestures or vocal inflection, which are lost when those same words are written, especially in a technical context. Consider the following particularly common mistakes in novice science writing:

- **Data**: more than any other word, *data* can be the most confusing to novice science writers. *Data* is the plural form of *datum*, though the singular form is rarely used. Traditionally, that would mean that you would write that "the data are" or "the data suggest," rather than "the data is." That said, it is starting to become common practice that the word **data** can be used in place of *the collection of data*, an uncountable collection of data. In this case, we would write that "the [collection of] data suggests" and "the [collection of] data is" (both in the singular).
- **Significant**: when used in scientific writing, significant/significance implies a particular outcome of statistical analysis (that your results are very unlikely to have occurred by chance). Novice writers often speak of their *significant* results; they are try to imply that results are important, but the term *significant* implies statistical relevance. Instead, the following words can be more appropriately used to convey your meaning: to indicate something of large effect (a big difference), use *substantial*; to imply the gravity or importance of a result, simply use *important*; and to convey the gravity of a result, try using *serious*.

Table 6.1. Selected words or phrases that are often used incorrectly or in a confusing manner.

Category	Example	Explanation	Sample Use
Comparison Words	**over/higher** vs. **greater/more than**	**Over** and **higher** are less accurate and also have spatial associations	"*more than 50ml was needed*" instead of "*over 50ml was needed*"
	fewer and **less**	**fewer** is used for numbered values, while **less** should be used for quantities (except when units are present then **less** is used for the number)	"*fewer than 10 fractions total*" versus "*less time was needed*" (exception: "*less than 10ml*")
Confused Words and Phrases	**affect/effect**	**Affect** means to influence, modify, or change. **Effect**, as a verb, means to bring about, but as a noun, means consequence, outcome, or result.	"*The decrease in temperature* **affects** *solubility.*" "*The exposure to sunlight* **effected** *the shelf life.*" "*The difference in solvent had a noticeable* **effect** *on the rate.*"
	whether or not	Only to be used to mean "regardless of whether."	"**Whether or not** *run times are increased, the accuracy will remain low.*" NOT "*It was unclear whether or not the run times should be increased.*"
	to comprise	Means "to contain" or "to consist of", NOT to be used as a synonym for "to compose."	"*A molecule* **comprises** *atoms.*" NEVER "*A molecule is comprised of atoms.*"
Subordinating Conjunctions	**while** and **since** vs. **although/ because/ whereas**	**Although, because,** and **whereas** should be used to join subordinate clauses to the main sentence, because **while** and **since** have strong connotations of time.	"**Although** *the initial method was easily perturbed by small variations in weight, the final implementation was considerably more robust.*"

- **Hypothesis** vs. **theory**: a *hypothesis* is a proposed explanation made on the basis of limited preliminary observations or evidence, usually as a starting point for further investigation, whereas a *theory* refers to a set of principles or system of ideas intended to explain something.
- **Can't** vs. **cannot**: While not necessarily a source of confusion, **contractions** are discouraged in scientific writing.
- **Efficacious, utilize, elucidate, and proximal**: while none of these words are incorrect, they are usually unnecessarily complex. When given a choice between a familiar and a technical (or obscure)

term, the more familiar term is preferable if it doesnt reduce precision. Consider using the following as alternates: effective, use, explain, and close.

Additional examples of words and phrases that are often confused, or used incorrectly, are tabulated in Table 6.1.

6.2.2 Wordiness

In science writing, it is preferable to always be clear and direct. Superfluous descriptors and excess (often redundant) words can confuse the reader and obscure your findings. Additionally, there are page limits on most journal submissions, so being economical with your words is often a necessity. Better to write with a clear and precise meaning as you go, rather than have to come back and reword things later.

That said, sometimes longer phrases are used in good rhetoric. Use these longer phrases for emphasis, and only sparingly. Consider the following examples of good places to reduce wordiness:

- "*a few*" instead of "*a small number of*".
- "*although*" instead of "*in spite of the fact that*".
- "*because*, *since*, or *why*" instead of "*the reason for*, *due to the fact that*, *in light of the fact that*, *given the fact that*, and *considering the fact that*."
- "*if*" instead of "*in the event that* and *under the circumstances in which*."
- "*must* or *should*" instead of "*it is necessary that* and *cannot be avoided*."

6.2.3 Sentence construction and word order

Here are some of the more common ways in which sentences are improperly constructed:

- **Too many short declarative sentences.** Although they are often the most clear to read (and easiest to write) you do not want your writing to suffer from poor flow and cause a disconnect between ideas. Try combining very short sentences to help related ideas move smoothly.

- **Ambiguous pronouns.** When you use a pronoun, make sure that the noun to which the pronoun refers is clear. Ambiguous pronouns are most often seen when using **this** and **that**. Be sure to include the noun if there is a possibility of confusion.

Example 6.3: Ambiguous pronouns

Incorrect:	The reaction was complete when an orange precipitate formed and it was collected via filtration.
Correct:	The precipitate was collected by filtration and provided 417 mg of the orange product with 53% yield.

It is not clear in the first sentence to which noun 'it' is referring.

- **Double Negatives.** While double negatives are sometimes used as a stylistic nuance to indicate an understated affirmation, they are not considered proper in scientific writing.

> Example 6.4: Double Negatives
>
> *Incorrect:* The difference in absorbance values was not unexpected.
>
> *Correct:* We knew it was possible for the absorbance values to differ.
>
> Use affirmative language rather than a double negative.

- **Restrictive Expressions.** If a phrase or clause is necessary for the sentence to make sense it is *restrictive*. *Restrictive clauses* should be introduced by **that** not **which**. A phrase or clause is considered *nonrestrictive* if the information added is not essential. Nonrestrictive clauses and phrases are set off by commas and can be introduced using **which** (or **who**). A good way to tell the difference is if you deleted the clause/phrase, would the sentence still actually make the intended point to the reader or relate the desired information?

> Example 6.5: Restrictive Expressions
>
> *Incorrect:* "Before titration could begin the flask was lowered to a temperature which would prevent evaporation."
>
> "Plotting all four of the UV-Vis curves that are shown in Figure 3 allowed us to select the optimum starting concentration."
>
> *Correct:* "Before titration could begin the flask was lowered to a temperature **that** would prevent evaporation."
>
> "Plotting all four of the UV-Vis curves, **which** are shown in Figure 3, allowed us to select the optimum starting concentration."
>
> The first example is clearly restrictive because if the clause was deleted it would not convey the importance in lowering the temperature, or to what sort of temperature it was lowered. In the second example the clause simply lets the reader know that this information can also be seen in a figure, but still explains the main point without it.

- **Misplaced modifiers.**
  - **"Based on"** vs. **"on the basis of":** *Based on* is used to modify a noun or a pronoun (often immediately preceding or following), while *on the basis of* is used to modify a verb. Think of it as *something* can be **based on** *something else*, whereas you would *do* something **on the basis of** *something.*

- **"Due to":** This phrase is used to modify a noun or pronoun directly before it in the sentence OR following a form of the verb "to be."
- **Split Infinitives.** In non-technical writing split infinitives are accepted as grammatically correct, this is not the case in scientific writing. A split infinitive allows a statement to be interpreted in multiple ways. In science writing this varied interpretation is what you are trying to prevent by choosing the words carefully.

> Example 6.6: Spit infinitives
>
> *Incorrect:* Each data point was carefully measured after the initial sample preparation.
>
> *Correct:* Each data point was measured after the initial sample preparation.
>
> Removing the adverb 'carefully' removes the split infinitive.

- **Commas.** While in the United States it has become common practice to omit the comma before the word 'and' in a list of three items (this is called the "Oxford comma"). In fact, there are some that argue that the Oxford comma is actually *incorrect* in the US. Unfortunately, the absence of the serial comma in a list of three items can lead to substantial ambiguity. In science writing, as it is in all writing in the **rest of the English-speaking world**, the Oxford comma is mandatory.

> Example 6.7: Commas
>
> *Incorrect:* For breakfast today, I ate eggs, toast and juice.
>
> Cobalt complexes are important, industrial compounds.
>
> *Correct:* For breakfast today, I ate eggs, toast, and juice.
>
> Cobalt complexes are important industrial compounds.
>
> The first sentence was incorrect because it was missing the serial (or "oxford") comma - the ambiguity in the first version is that it is possible to imagine that the juice was on the toast, rather than with it. The second sentence was incorrect because commas can only be inserted between two or more adjectives if the adjective order can be reversed without losing meaning.

6.3 Lessons from experts in the field

There is no substitute for the experience that comes with writing, **and reading**, scientific papers over the course of a number of years. Two of the more important lessons are (a) that you need to know how people read scientific papers before you can write a good one, and (b) that each section of a paper will stand on its own – there is no need to read through a whole paper.

6.3.1 Reading scientific papers

Part of being a research-active scientist is keeping-up with advances in the field by reading the scientific literature. Rarely will someone who is browsing the scientific literature read an entire paper from start to finish. Rather, we tend to start by reading the Abstract (to be discussed in a later assignment). After the Abstract, the next stop is the conclusion section and a look at the pictures (figures, tables, etc...) — the remainder of the paper would only be read if those seem interesting.

6.3.2 Each section stands alone

Often we are reading a paper for a very specific purpose. For example: to extract some necessary data (Results), to glean some understanding of an important/interesting phenomenon (Discussion), or to learn how to perform a specific procedure/synthesis (Experimental). Notice that none of those reasons require the reader to agonize over the entire paper; rather, we will often only read the section(s) of the paper that are necessary for our purposes.

Consequently, it is important that each section be able to stand alone. The Introduction section will always contain the motivation and objective of an experiment, as well as a description of the general approach taken to solve the scientific problem. The Conclusion section begins by summarizing the overall success/failure of the experiment. All that remains is to provide a brief and concise summary of the problem to be solved at the beginning of the Results and Discussion. The captions of tables and figures (or a rephrasing of them) appear in the text as the table/figure is being discussed.

6.4 Putting it all together

Although the mistakes and tips discussed above will probably not often be explicitly looked for in grading considerations, their proper implementation will only serve to improve the quality of your writing and your grade. If a grader is able to easily read your assignment and find the relevant information, there is no risk of lost points due to simple lack of clarity (not to mention a reader who isn't frustrated by confusing sentences and conflicting information will probably be a little more generous in their evaluation!). Writing well also helps you as a scientist, since you must thoroughly think about how concepts relate or what results mean in order to create logical, smooth flowing sentences about them. If you haven't thought about what a result means in the context of the experiment you just ran, it is very difficult to convey it to someone else.

End-of-chapter assignment

1. Identify the problem(s) with each of the following writing samples and propose a correct version.
   (a) The resulting mixture is a heterogenous solution, but is mainly comprised of hexane.
   (b) Because of the compound's sensitivity to light, it is not uncommon to see a slight decay pattern over time that is depicted in Figure 5.
   (c) We weren't able to determine the identity of the complex strictly by color, since there was more than one ion complex that could have been green.
   (d) The uncertainty introduced into the experiment due to wet glassware probably had the large effect on the final results, which is seen the large percent difference from the literature value.
   (e) The average of the three trials from the UV-Vis method was 6.9832± 0.004mg. The Average of the three trials in the AAS method was 7.82± 0.45mg. One point from each method had

to be dropped because it failed the Grubbs test, meaning it was an outlier relative to the rest of the data. A Student's T test was also performed to compare the results of the data of both methods. Both methods were compared to the literature value of 7.0mg/L. [8] The average for the UV-Vis method had a value less than t_{table}, meaning that are statistically similar. The AAS method had a value that was greater than t_{table}, meaning that it failed.

2. Give a copy of your last Abridged report to a friend in your class (someone that you trust and who you respect) and get a PDF copy of their paper.
   (a) Find and list two things (sentences, paragraphs, etc...) that you feel they did especially well. What about them do you appreciate?
   (b) Find two places where you feel they could have made better grammatical or word choices. Suggest a better version for each.
   (c) Find and list two things that you would improve about their paper. Do not include places where you feel they could improve their grammar or word choice; rather focus on the organization, presentation, and content of their paper. Explain each briefly (in no more than one sentence).
   (d) Do you feel that they have made a convincing argument? Explain briefly (no more than a couple of sentences).
   (e) Do you feel that they have written a concise paper that follows a logical flow? Do you feel that it is pitched towards an appropriate audience? Explain briefly (no more than a few sentences).
3. For your most recent lab:
   (a) After completing your data analysis, answer the "seven questions" (see chapter #3) to help you plan your argument.
   (b) Propose an *Argument Summary* for your paper; tabulate the data and exhibits that you prepared in your analysis and indicate where in the paper (or Supporting Information) these would be included; and prepare a checklist that you will use to write your Abridged report (you do not need to include Introduction and Experimental sections).
   (c) Based on your argument summary and table of data, use the information in this chapter (and all of the previous chapters) to write an Abridged Report (make sure to include your argument summary and checklist).

7

Introduction Section

The Introduction section of a scholarly paper can often be overlooked by the author. Focused on the innovation that the author is trying to communicate, this very important component can sometimes be relegated to an after-thought. In reality, while nothing groundbreaking will be presented in the Introduction, it serves as both the 'catch' that grabs the attention of potential readers and as the foundation upon which the scientific breakthrough is presented. Your paper, as excellent as it may be, may never actually be read without a good Introduction – of course, your lab instructors will always read your papers in this class!

7.1 Content and Organization

In general, the Introduction is broken down into three specific components:

1. **Introducing the research area:** the first few lines of the paper are used to generally describe the research area and to motivate the work. This component is further divided into three subcomponents:

   (a) *Identifying the research area:* what is this paper going to be talking about (very general)? This is usually accomplished in the first sentence of the paper. Be careful not to be too catchy - we are writing for an expert audience, not for a general audience.

   > Writing Sample 7.1: Identifying the research area
   >
   > "*Chlorofluorocarbons* (CFCs) are a group of organic compounds, containing chlorine and fluorine, that have been found to be linked to the depletion of the ozone layer.[1]"
   >
   > This is an example of the first sentence of a paper being written on research in the general area relating to chlorofluorocarbons. Notice: the actual topic of the research is NOT presented here. It will be presented in component 3 of the Introduction.

   (b) *Importance of the research area:* why is this area important? What is the motivation for studying this topic? In general, it will suffice to include a couple of sentences detailing the reason why the topic is of such high importance. Consider reading the Introductions of other scholarly papers on the same subject to see why other people consider the area to be significant.

(c) *Essential Background about the area*: a terse summary of the current state of the art in the field - this should not be exhaustive. Rather, this is used to provide enough information to give the reader a good understanding of the field. Use relevant literature sources to explain what has been done in the field to date and explain the methods that are used in the experiment.

> Writing Sample 7.2: Importance of the research area
>
> "In that past, many CFCs were widely used as refrigerants, propellants, and solvents[1]. The manufacture of such compounds is being phased out by the Montreal Protocol[2] because it **has been shown** that CFCs ..."
>
> Continuing the example from above: the importance was already hinted at in the first sentence (ozone depletion), but is elaborated upon in this sample. Notice: references must be brought to substantiate any claims made in this portion of the paper.

2. **Identifying a gap:** once the field/area has been adequately introduced (discussing the work already done), we shift towards thinking about what needs to be done. Here, the author introduces/justifies the need for the body of work in the paper.

   It may be difficult to identify a genuine gap (one that actually exists in the current scientific knowledge) for some of your labs. For instance: it may be very difficult to pinpoint a reason why someone needs to measure Avogadro's number (Lab 1). This will be discussed, in detail, later on in this chapter.

> Writing Sample 7.3: Identifying the gap
>
> "Although mass spectrometry (MS) achieves the desired detection limits for ozone[2], the instrumentation and methodology is costly and time-consuming.[3]" or "The depletion of ozone by CFCs has been the subject of several studies[4]; however, no studies to date have been reported on the use of ..."
>
> Both of these samples are examples of a good gap statement. In the first the gap being described is about a procedure that needs to be improved (made simpler or cheaper), while the second is an example of an area that needs to still be explored.

3. **Introducing the current work:** after the field has been introduced and a gap in the knowledge has been established, the final component is to describe how this paper will fill the gap. This is the last paragraph of the Introduction and will typically start with "In this paper, ..." and will provide a *brief* description of the general approach that was used to perform the scientific inquiry. Remember: the use of the first person, or *we*, is discouraged in chemistry writing.

7.2 Format and Style

The Introduction should consist almost entirely of prose. Relevant chemical equations can be included to accomplish one of the goals listed above (motivation, survey of the field, etc...). Similarly, figures from the literature or that support the goals can also appear.

Every scientist will eventually develop their own writing style. While there are many areas in which these can differ, there are some stylistic criteria that are universally accepted. Consider the following (incomplete) list of considerations for the Introduction section:

- You are writing as scientists, not as freshmen students. The objective of the lab is never to 'calibrate a pipette' or 'learn Beer's Law'. In other words, the *Objective* that you wrote in your lab notebook is unlikely to be the Motivation that you are writing about in your introduction.
- By the nature of the types of statements and arguments that need to be made in the first two components, you will need to provide a decent number of references in the Introduction. The third component will not require citation unless it is building off of work that you have already published.
- Don't rely on random facts and certainly never use aphorisms like "it is well-known that ..." Rather, make sure that your argument (motivation) is focused and supported by references from the primary (journal articles) or secondary (review articles, book chapters) sources in the scientific literature. Reminder about Internet references: these are to be avoided, where possible. Recall, however, that journals and books that are accessed online are not 'internet' references and should be cited as journals and books (no URLs).
- Don't be too 'on-the-nose' when writing your Introduction. Often, novice science writers would include statements such as "The objective of this experiment was ..." Instead, consider a more elegant version, such as "Given the need for, ..." or "Given the importance, ..." Stylistic elements like these will make your argument stronger, because it will not sound like you are trying to check-off components from your checklist (though, in reality, you are).
- Remember: less is more.

7.2.1 Voice and Tenses

The beginning of the Introduction, especially when discussing the importance of the research area, is often written in the *Present Perfect*. The Present Perfect is typically used to indicate work that was done in the past that is still considered to be true in the present. Notice the bolded words in Writing Sample 7.2 - this is an example of present perfect in the passive voice. In general, when referring to work done by others (in the past), either the *Present* or *Present Perfect* tenses should be used:

Example 7.1: Proper tenses for citing work

Incorrect: Abrams et al. demonstrated that CFC levels can be easily ...

Correct: Recent advances[3] have led to a method for ...

The first version is written in the past tense and is not correct. The second version is written in the Present perfect in the active voice and is a correct way of citing their work. Additionally, notice the correct use of citations in the second version. Note: in general, try to avoid mentioning research groups by name.

The final component of the introduction, describing the work that was done, will contain both the past and present tenses, where appropriate. The work done *in the past* should be described in the past tense ("the structure was determined by ..."), while the truths that are gleaned from the research are in the present tense ("the structure indicates that ...").

7.2.2 Length and Depth

It is important to remember to be concise without being terse, and complete without containing semi-relevant or irrelevant information. **Less is more**. Do not use more sentences, or overly verbose clauses, in order to increase the length of your paper. You will not be assessed based on the length of your paper, rather by its quality and completeness. Moreover, it is completely inappropriate to write more than is necessary.

Finding this balance can sometimes be hard for a novice science writer. We've already run into this problem with our Results and Discussion sections. You'll recall that we discovered that preparing a good, complete checklist **before** starting to write the paper is extremely helpful when it comes to being complete and concise.

For the purposes of papers that you will write in CH111/112, you should **limit** your Introduction to about one double-spaced page[1] (unless otherwise specified) – the length should be commensurate with the amount of information that must be communicated. It is not appropriate to have unnecessarily lengthy Introductions. That said, though the page limit may seem restrictive, it is also important that the Introduction flow well from paragraph to paragraph. It should not seem like you are simply checking off components from a list; rather, make sure to utilize appropriate segues in order to connect ideas.

7.3 Argument and Introductions

The Introduction section is the component of the paper in which the author motivates the science. The goal of the introduction is to captivate the reader on two levels: by demonstrating the research area is significant and interesting (motivation), and by showing how *this specific study* contributes something novel and crucial to the field (gap). Revisit Assignment #3 to review Arguments and Argument Summaries.

It should be noted, however, that in CH111/112 we will not really have any true "gaps," with the exception of the Capstone project. Since it would be inappropriate to invent a fake gap statement, we will replace this component with an *Objective statement*.

> Writing Sample 7.4: Gap vs. Objective
>
> *Gap*: "The depletion of ozone by CFCs has been the subject of several studies[4]; however, no studies to date have been reported on the use of ..."
>
> *Objective*: "Given the need to quantify CFCs in atmospheric samples, this study demonstrates how ..."
>
> The 'gap' version indicates that the paper will discuss a novel approach to the problem, whereas the 'objective' version does not.

7.4 Common Mistakes

The most common mistakes that people make when writing their Introductions are:

[1] Though shorter than one page is perfectly fine. Just remember to include the three necessary moves and sufficient detail.

- Writing the Introduction too early! This section should be written last (except for the Title and Abstract), once it is clear exactly what direction the paper will take. Writing Introductions too early usually results in unnecessary rewriting.
- Using style-inappropriate terms such as: *we looked into*, *we saw*, or *researchers* (these should never be used). *Research* may be used sparingly, but is not recommended.
- Using the the term *current work* improperly. In the context of a scientific paper, *current work* refers to the author's work that is being presented in that paper (not in the literature).
- Presenting results in the Introduction. Remember, this is not an Abstract. The Introduction is for talking about the goals and the current state of the art.

Example 7.2: Introduction (1)

Incorrect: "Red socks were washed with Downy and Target detergents for 5.5 minutes each at 70°C . Stains were removed $78.5 \pm 0.1\%$ of the time with Downy detergent and $89.6 \pm 0.2\%$ using Target detergent."

Correct: "In this work, the removal of chocolate stains on red socks using a washing machine is investigated. This was done by washing red socks with a variety of detergents for various lengths of time using ..."

In the first version, results and unnecessary experimental details are provided. In the second, the objective was discussed.

- Providing too much detail vis-a-vis the experimental details in the Introduction.

Example 7.3: Detailed vs. General

Incorrect: In this work, the ozone concentration in a 1.0 L gas sample was determined by aspirating 10.0 μL into an Agilent 1080 GC-MS with column temperature static at 200°C.

Correct: In this paper, a method for measuring ozone concentrations in gas samples via mass spectrometry is presented. The analyses were performed on a GC-MS equipped with an electron capture detector (ECD) in order to achieve more accurate results in half of the time.

There should be little repetition in journal articles. The first version is appropriate for an Experimental, in which precise experimental details are provided. For an Introduction, it is better to simply describe the general approach (second version).

- Not citing enough literature sources - many Introduction components require citations. Citations are required any time you present information that is not scientific common-knowledge.
- Using direct quotes. While direct quotations are common in other forms of writing, this practice is rare and highly discouraged in scientific writing.

7.5 Overall Considerations for Introduction Sections

There are a lot of details to consider while you are writing your Introduction. Consider the following:

- A good argument summary and a good checklist - prepared before starting to write - are necessary to achieve a cogent, meaningful Introduction.
- The most important thing to learn is the correct Content and Organization. After organization, the flow and proper formatting is important.
- Don't forget to always look over your work with a critical eye for the 'common mistakes.' They are so named because they are very common!
- References are usually needed for each component of the Introduction. Make sure to include all of the necessary citations. Remember: if you used a source to help guide your understanding/preparation, then you need to cite it. The Introduction to a strong paper usually requires a good amount of research.

7.6 End-of-chapter assignment

1. Review the major ideas in 'What to avoid in scientific writing' (Section 4.1) and 'Writing like a chemist' (Chapter 6). Think back to your old science writing (perhaps from High School or another science class), specifically to how you would have written an Introduction section, and suggest two items that you will change/eliminate when you write your Introduction sections. Explain very briefly.
2. Prepare an argument summary and checklist for your paper (IRDC – Introduction, Results and Discussion, and Conclusion). Submit your table of data, argument summary, and checklist, with your paper. **Note:** consider following the suggested order below.
3. Use the information in this chapter, the checklist you just constructed, and all of the assignments to date, when writing your paper (IRDC).

Suggested order for approaching the paper:

1. Start by identifying each of the following for your experiment: a scientific motivation for the experiment, the objective of the experiment, and the educational purpose of the lab.
2. Consider all of the data collected in the experiment. Tabulate the data that is relevant for this lab and assign them as raw data, processed, or statistic. Indicate where you intend to include this data in your report.
3. After examining the Results of your experiment, do enough research to make sure that your satisfied that you understand your results (why you got them? what they mean?). Prepare an argument summary for the Results and Discussion section.
4. Based on your argument summary and table of data, prepare a checklist for the Results and Discussion, Conclusion, and Supporting Information sections.
5. Now that you've outlined the Results and Discussion of your paper, it is time to start thinking about the Introduction. Identify the following components and add them to your argument summary: motivation and gap.

6. Based on your complete argument summary, add the Introduction components to your checklist. Consider using a table (like the one below, though yours will likely have more than one specific aim) for your checklist. Notice that the table leaves room for the references that you used for **each** component of the proposal.

Required Component:	**Reference**
(1a) The research area is ...	
(1b) This area is important because ...	
(1c) Background info that needs to be included about area:	
(2) The "Gap" is ...	
(3a) In this paper ...	
(3b) (The general approach was ...)	

7. Re-read your argument summary and your checklist to make sure that your paper will make sense and present a strong argument. You are now ready to write your paper.

8

Experimental Section

The Experimental can be very difficult to write well. There needs to be a balance between a good amount of detail and readability. The sole purpose of the Experimental section of a scientific paper is to convey the exact method by which the experiment was carried out. An appropriately-pitched Experimental will omit the details that any novice would know (such as how to take a mass by difference or clean a burette) and provide enough description, observations, and details to sufficiently guide an expert to be able to successfully repeat the experiment.

Additionally, the Experimental section can often suffer the most from the problems of bad writing or not being concise. Make sure to reference the assignments on how to properly 'Write like a chemist' when writing your Experimentals.

8.1 Content and Organization

In general, the Experimental will not include information that belongs in the Results, such as spectral data and crystal data. For synthetic papers, yields are often presented in the Experimental.

It is important that the Experimental be complete with the details that another scientist would require in order to reproduce the experiment. These include:

- Exact masses of reagents, when they are relevant. Report the actual amounts and concentrations that you used. Do not use the approximate amounts like those that would be listed in a lab manual.

- Types/purity of reagents. Avoid using brand names; generic names are more appropriate. In the event that the purity of the reagents would affect the experiment, make sure to discuss the purity or origin of the reagent. Similarly, if the reagent needed to be standardized, this might be included.

- Descriptions of apparatus that are not standard. Only describe an apparatus if it is not a standard, or well-known, apparatus. Provide the make and model of analytical instruments such as spectrophotometers, meters (pH, mV), and diffractometers. Do not identify the specific standard equipment (pipettes, flasks, burettes, etc...) – it is clear by the number of significant figures in the amounts, the context, and convention which pieces of glassware would be used to dispense solutions.

- Key observations. Make sure to include key, or milestone, observations that would allow someone to know that they are on the right track or have correctly achieved the desired result. (*e.g.* "Adding the acid caused the clear, colorless liquid to turn immediately cloudy." or "Some small crystals remained at the bottom of the flask, even after heating.")
- Only emphasize or mention the hazards and safety concerns that would not be standard protocol in a lab.

8.1.1 Special Subsections

In many journals there are two special subsections of the Experimental section: 'Reagents and Materials' (or 'Materials and Methods') and 'Statistical Methods' (or 'Data Analysis'). The Reagents and Materials section is the first subsection of the Experimental and is where all of the pertinent information about the chemicals (from where? standardized?), instruments, and techniques can be found.

> Writing Sample 8.1: Materials and Methods
>
> "**Material and Methods.** All solvents and reagents were provided by the Boston University Analytical Chemistry stockroom and were used as received without further purification. Solids were massed by difference on analytical balances and solutions were dispensed using calibrated volumetric glassware. Temperature measurements were made with a Noname digital thermometer... "
>
> The materials and methods subsection of an Experimental will give all of the preparatory information that someone would need to know in order to start repeating the experiment.

The Statistical Methods (or Data Analysis) section is the last subsection of the Experimental and is where all of the post-processing of the data is discussed (Grubbs test, Buoyancy scaling, peak integration, etc...). From here the reader is able to understand how you were able to take your experimental data and derive the results that you are about to present. Of course, rarely are sample calculations presented; unless those calculations represent the novelty of the study.

Using these sections can make the rest of the Experimental section substantially easier to read and much less cluttered.

8.2 Format and Style

The Experimental almost always consists solely of paragraphs. Diagrams of rare, or new, apparatus should be included as well. In rare circumstances, such as the preparation of a series of solutions with small variations, a table can be helpful to minimize unnecessary repetitiveness.

For experiments with several parts, the Experimental section of the paper is broken down into subsections. This practice makes the Experimental much easier to read and it will make it easier for someone to reproduce the *part* of experiment in which they are interested.

In order to distinguish these subsections, the first few words of the paragraph beginning the subsection should be in **bold** (see Writing Sample 8.1); we do not use "Part .." in these headings. There is no limit to the number of subsections that you can use, but they should be consistent with the number of parts of the experiment you performed (synthesis, analysis, etc...).

Some additional formatting guidelines:

- No bullets — this is not a procedure in a lab manual.
- When using a standard method, cite the literature.
- When part, or all, of the experiment is taken from another source (a lab manual, for example) then it is appropriate to cite the entire Experimental.
- Include the observations within the procedure when they are relevant or important.
- Be careful with amounts and units – a space is always placed between the amount and unit.

8.2.1 Voice and Tenses

The Experimental is always written in the past tense and passive voice. A primary aspect of the argument being made by a journal article is that the science performed is completely objective and independent of the researcher. Prose written in the past tense and passive voice gives the impression that the experiment could be carried out by anyone, and that anyone performing the experiment would have achieved the same results.

Additional grammatical concerns include:

- Sentences should never begin with a numeral (0 - 9). If you are reporting an amount, options for starting these sentences include: "A 5.00 g sample of ..." or "Sodium chloride (5.00 g) was ...". Both are correct.
- Proper grammar dictates that counting numbers less than ten (10) be written as words rather than numbers. This does not apply to measurements.
- Always put a zero before a decimal point (0.1, not .1). This is not limited to science writing; this is just proper number formatting.
- Never refer to "students" or "the experiment."

8.2.2 Length and Depth

There is no maximum length for the Experimental section. That said, instructions should be concise and to the point. Do not add unnecessary flourishes to make it "sound better." Short and to the point is best (less is more).

Example 8.1: Sentence Consolidation

Incorrect: "A 5.00 g sample of $Fe(NO_3)_3(s)$ was weighed on a balance. The solid was transferred to a 100 mL volumetric flask. A 20 mL volumetric pipette was used to add 20.00 mL of $0.1M$ nitric acid to the flask. Water was added to the volumetric flask until the mark. The final solution concentration was found to be $0.05M$."

Correct: "A 100-mL $0.05M$ $Fe^{3+}(aq)$ solution was prepared using 5.00 g of $Fe(NO_3)_3(s)$ and 20.00 mL of $0.1M$ nitric acid."

Both statements communicate the exact same procedure. The second version, which is much better than the first, is consistent with what we'd expect to see in a scholarly paper, while the first looks like a Procedure from a lab manual that has been written in the passive voice. Note: presumably the author of the second version has already mentioned any relevant quantitative techniques in the Materials and Methods subsection.

Equally important is the need to be complete - do not omit important details in the name of brevity.

8.2.3 Identifying Equipment

There are four classes of equipment that are discussed in a scholarly paper: standard (make/model are irrelevant), standard (make and model are important), non-specific, and novel.

- *Standard (relevant model)* equipment refers to instrumentation where the accuracy and precision will vary from model to model (Examples: spectrophotometers, melting point apparatus). This type of equipment will be referred to by make/model and should be enumerated in the Materials and Methods subsection.
- In the case of *Standard (model irrelevant)* equipment, while the author does need to specify the general type of instrument (pipette, flask, cylinder), the piece of equipment does not have to be identified by make and model in the report (examples: volumetric pipettes, graduated cylinder).

Writing Sample 8.2: Make and model (1)

"The absorbances of all solutions were measured at 510 nm on a CCD Array UV/Vis spectrophotometer that was blanked with deionized water."

Every UV/Vis spectrophotometer is built to different accuracy and precision specifications. Here, it is important to mention the exact make and model. Notice that this statement concisely describes the spectrophotometric measurements, as well as the relevant parameters: wavelength and blank.

- *Non-specific* instrumentation includes analytical balances and thermometers. It is clear from the degree of precision reported exactly what class of either is used. It is not necessary to even mention the type of instrument.

> Writing Sample 8.3: Make and model (2)
>
> "A 5.0105 g sample of the product was dissolved to make a 100 mL solution."
>
> Notice that the equipment used for recording the mass and preparing the solution are not mentioned. There are two reasons: (1) presumably it was mentioned in the Materials and methods that all masses were recorded by difference on an analytical balance, and that all solutions were prepared with volumetric glassware; or (2) the 4 digits of precision could only have been measured on an analytical balance and an expert would know that solutions of precise volumes are made in volumetric flasks.

- Finally, *Novel* equipment is equipment designed specifically for the experiment being presented. For this type of equipment, detailed instructions and a diagram/figure are required. Sometimes, when the novel piece of apparatus is not the focus of the experiment, these details are presented in the Supporting Information of the paper.

8.3 Common Mistakes

The most common mistakes that people make when writing their Experimentals are:

- A big mistake is that students often write their Experimental as if it were a lab manual:

> Example 8.2: Experimental vs. Procedure
>
> *Incorrect:* "Add approximately 0.2 g of NaCl(s) to a volumetric flask."
>
> *Correct:* "A 0.2021 g sample of NaCl(s), diluted to 100 mL, ..."
>
> The first statement is more reminiscent of a lab handout instruction; it is written with approximate amounts and as an instruction (do this). The second version correctly reports the precise amount of solid used and does so in a passive voice.

- Also, remember that it is important to not be *too* vague. Important details must be included.

> Example 8.3: General vs. Specific
>
> *Incorrect:* "A bromine solution was added to the flask"
>
> *Correct:* "A 10.00 mL aliquot of bromine was added to the reaction flask containing the unknown, and the solution immediately turned orange."
>
> The first statement lacks quantization and specificity. How much Bromine was added? To what flask? What happened when you added it?

- One of the most substantial problems is when someone reports too much raw information, such as masses of weighing jars and paper:

> Example 8.4: Raw Data
>
> *Incorrect:* "A sample of NaCl(s) was weighed out in a weighing jar with mass 15.1000 g. The mass of the jar and NaCl was 15.3041 g. After delivering the NaCl to the reaction flask, the jar was reweighed at 15.1020 g. The mass of NaCl delivered was 0.2021 g."
>
> *Correct:* "A 0.2021 g sample of NaCl(s) was added ..."
>
> The first statement paragraph is verbose, clumsy, and unnecessary. The second version correctly, concisely, and properly reports the precise amount of solid used (presumably, the fact that the masses were by difference was mentioned in the Materials and Methods subsection).

- Proper convention requires a space between a value and the units.

> Example 8.5: Units
>
> *Incorrect:* "A 0.2021 gram sample of NaCl(s) was added to 15mL of ..."
>
> *Correct:* "A 0.2021 g sample of NaCl(s) was added to to 15 mL ..."
>
> Never spell out units (gram), and there should be a space between 15 and mL.

8.4 Past experiments in context

It can be very difficult, especially for novices, to get a good feeling for the level of detail that is expected in the Experimental section of a scholarly paper. To help illustrate, let's investigate a couple of past lab experiments and suggest how they could be approached.

- *Avogadro's number lab*: In Lab 1 we calibrated micropipettes and used them to calculate Avogadro's number using a monomolecular film of stearic acid. The entirety of the first part of the experiment, calibrating the micropipettes, would be a single statement in the Reagents and Materials subsection: "The 10 μL and 20 μL settings of a Fisherbrand micropipette were calibrated gravimetrically with water."

- *KHP titration lab*: This lab had two main parts: titrating NaOH solutions with KHP in order to determine the precise concentration and using the NaOH to determine the amount of KHP in an unknown mixture. The entire Experimental could be written as: "Samples of KHP-containing unknowns were titrated against standardized 0.1M NaOH to a phenolphthalein endpoint." The entire first part of the experiment is replaced with the word 'standardized' - any expert should know how to standardize NaOH, or they could purchase pre-standardized base. Additionally, the exact masses of the samples are only nominally relevant since we are determining the concentration, which is an intensive property (one that is sample-size independent). Finally, the number of trials need not be specified as the statistics will be presented in the Results section.

- *Stoichiometry of Mg and HCl lab*: Unlike the previous two examples, this lab would require a more elaborate Experimental. Here, at least three additional subsections (other than the Materials and Methods, and Data Analysis) would be required: (1) the construction of the syphon apparatus, (2) the reaction of Mg and HCl, and (3) the back-titration of the reaction mixtures. The last two subsections could be combined.

8.5 Preparing to write an Experimental Section

The Experimental section of a paper is the only section that truly 'stands alone.' While the strength of the methods used often contribute to the strength of the argument, it is rarely the case that the methods are a cornerstone of the Argument being made; the most glaring exception to this general idea is when the paper is focused on the development of a new method. As a result, the Experimental can usually be written in parallel to the rest of the paper.

It is challenging to sort out what details are important, especially if you are trying to do so as you write. A suggestion to help guide you in your preparation of your Experimental sections, it is helpful to use a table to sort out the different subsections that you will use, and help determine what details are necessary to include and which details should be omitted.

To illustrate the power of this approach, let's consider the cobalt-complex lab that we've already performed. A suggested breakdown of the Experimental is tabulated below.

Subsection:	**Necessary Information**	**Unnecessary Information**
Materials and Methods	- Source of the cobalt complex - Exact ion-exchange resin used - Length of ion-exchange column	- Specific glassware used - Source of chemicals (other than the complexes)
Determination of outer-sphere chloride ions	- Sample-size of complex - Care was used to avoid heat - Chromatographed to remove complex - Neutralized to pH 7-8 using Na_2CO_3 - Amount of dextrin added - Titrated to fluoroscien endpoint	- Volume of mobile phase used - Exact mass carbonate used
Ligand exchange and determination of total chloride content	- Sample-size of complex - 6M ammonia added and heated for X mins (exact time and amount) - Chromatographed to remove complex - Statement to see previous section for titration details	- Volume of mobile phase used

8.6 Overall considerations for Experimentals

Experimentals are somewhat difficult for novices, as the level of detail needed is often something that requires time and experience to master. Consider the following when working on your Experimental:

- Use a good table to outline your Experimental; the goal is to help you to decide on the pertinent details to include in, or exclude from, your Experimental.

- At a minimum you should use correct verb tenses, use experimental values (not approximates), and write your section as prose.

- The most important thing to learn is the correct Format and Organization. Experimentals that are written as glorified procedures, or without good structure, are inappropriate. Use the special subsections, where relevant, to improve the quality of your Experimental.

- Don't forget to always look over your work with a critical eye for the 'common mistakes,' and to apply the lessons from the previous assignments on proper conventions and grammar of science writing.

8.7 End-of-chapter assignment

1. Consider the following excerpt from an Experimental section:

   For the purpose of standardizing KMnO4 for quantitative titration, a burette was filled with .02 Molar KmnO4. After it was found that no air bubbles were trapped in the tip of the pipette, the initial volume was recorded. Using a weighing bottle, exactly 0.2315g were weighed out. Fifty mL of 4.5 Molar sulfuric acid, 200 mL of distilled water and the massed out sodium oxalate were added to a 400 mL flask. The solution was stirred until all of the solid dissolved. Approximately 30 mL of KmnO4 was added to the solution. The solution turned dark purple. The solution was than continued to be stirred due to the fact that the titration was incomplete. Once the solution becomes clear, place it on a hot plate in a fume hood and heat it until it's temperature was between 55 and 60°C. While the solution was still warm, the titration was completed by adding KmnO4 until a significant amount of pale pink color persisted, and the end volume was then recorded. The data were recorded in the lab notebook.

   (a) Using the information in the earlier chapters on conventions and practices in scientific writing, identify at least five "writing" issues with the passage (sentence construction, word choice, grammar, concision, etc...). Do not include style, format, or chemistry errors (from this chapter). For example: in the sentence beginning "Once the solution", the word "it's" should be "its."

   (b) Based on the information in this chapter, identify at least five issues with the style, format, language, or chemistry of the Experimental section excerpt. For example: .02 should be written as 0.02.

   (c) Write a version of this excerpt that corrects all of the grammar, stylistic, and chemistry convention issues. You should assume that the appropriate Materials and Methods section precedes the passage.

2. Reproduce the table below on your computer, and use it as a template for a checklist for an Experimental for a recent lab. The two special subsections and one additional subsection are shown - use as many subsections as you need / deem necessary.

Subsection:	**Necessary Information**	**Unnecessary Information**
Materials and Methods		
Data Analysis		

3. Use the checklist you just constructed when writing your Experimental section for the lab you chose.