Undergraduate's Guide to Writing in the Sciences

Version 0.9, pre-print

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PREFACE

Origin of this writing guide

This writing guide began in 2009 as a series of handouts designed for the Intensive General and Quantitative Analytical Chemistry courses at Boston University. The goal was to present students beginning college with all of the guidance and support that they would need to start developing as scientific writers, without too much excess information.

Over the course of the decade that followed, the scope and material in those handouts was expanded until they evolved into a full writing guide. Fast forward to 2018, the writing guide helps support all of the chemistry majors at the university as they work through their major. Most of the chapters remain designed to stand alone for use in specific courses; as a result, there are places in this guide where information is repeated by design. In each of those cases, the content being repeated is of particular importance and relevance.

Philosophy of writing instruction

Good science writing means good writing. While there are many discipline-specific nuances and conventions unique in the sciences, the principles of formal, technical writing do not differ so greatly between any of the academic disciplines. In the end, a foundation in strong research and argumentation is the necessary pre-requisite to effective science communication.

Developing your style as a technical writer is something that will happen over a long period of time. Throughout your years as an undergraduate student you will investigate the skills at the core of good scientific communication: research, argumentation, visual display of information, and more. As you progress from course to course as an undergraduate student, and as you matriculate into graduate programs and careers, these principles will remain at the core of the work that you do to evolve your communication and writing ability.

Branching out into other disciplines

While there are structural and stylistic differences in the writing among the science disciplines, the vast majority of STEM communication is based on a common set of broad principles and skills. In 2019, Dr. Kathryn Spilios of the Biology department joined the project with the goal of extending the guide from a chemistry writing to guide to one that would meet the needs of all undergraduate science students at Boston University.

Throughout the guide, we remain focused primarily on the overarching principles that are common to all scientific communication. In cases where distinctive, discipline-specific differences are important, specific mention is made to the ways in which the different fields approach the subject and the reasons behind the differences. You should view this guide as a tool to help you be a better scientific writer in general, rather than an expert in your specific field – after all, the goal of writing is effective communication, regardless of discipline.

Examples of good (and bad) writing are brought from several scientific disciplines throughout the writing guide. While the chemistry examples are highlighted in purple and the biology examples are highlighted in red, we encourage you to focus on context of the examples rather than content.

Example 0.1: Chemistry examples

Boxes outlined in purple will highlight examples and general considerations related to chemistry.

Example 0.2: Biology examples

Boxes outlined in red will highlight examples and general considerations related to biology.

General Considerations

Green boxes will present general ideas about writing, especially when differences between scientific disciplines or agencies vary.

Using this writing guide

There are three main parts to this guide. Important background skills related to scientific writing are presented in Part I: preparing effective exhibits for your papers, research, and argumentation. Part II is dedicated to writing journal article style papers, starting with the most important section: the Results and Discussion. Finally, other genres of scientific communication, such as research proposals and conference presentations, are discussed in Part III.

Version 0.9 of the guide

If you're reading this, then you are working from a pre-print of the first edition of the guide (version 0.9). We are still hard at work editing, refining, and adding material. To that end, we would be grateful for your help! Please let us know if there is anything you find confusing or missing. Similarly, while we don't expect you to be our copy editors (we're looking into finding one now), we are grateful for reports of any mistakes, typographical errors, or omissions. Please direct your comments to `STEMwritingguide@gmail.com`

Thank you for your interest in science writing and the guide.

Binyomin Abrams
Boston, 2021

Part I

Tools of the Trade – Writing isn't just writing

CHAPTER 1

INTRODUCTION TO SCIENTIFIC WRITING

Before we can begin discussing the skills and details of scientific writing, we must first preface with a little bit of background about technical writing for the sciences, and how scientific writing differs from other writing styles. While scientific writing shares many common aspects with other forms of argumentative writing, discipline-specific conventions and nuances also play an important role. This guide provides details on practices important in writing across scientific disciplines.

1.1 Why do we 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 but 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 are relevant to a career scientist. Grant proposals are the main vehicle by which scientists petition funding agencies 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 through 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 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 collaborative. 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, or journal article, is the vehicle of persuasion. After the paper has been submitted, it is given 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.

1.2 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 specific 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 are 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 that reason that we will not teach 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. This approach is geared toward making students good scientists, rather than just good students.

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 study. 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 modern 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 formulas 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 to the broader scientific community. When discussing the validity and consequence of these results, it is critical that the argument presented be compelling. Lab reports, however, are usually seen as a vehicle for the reporting 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.

- *Appropriate references:* in writing scientific papers, previous work and background information are always referenced. The only appropriate sources for reference in scientific studies are authoritative sources such as journal articles (in peer-reviewed journals), books, and scientific databases. A scientist will never use information, and therefore will never cite, random internet sites in their work. Here, "internet sites" refers to private websites, or non-peer-reviewed information, such as Wikipedia, random websites, and even course academic sites at universities. Books accessed online (such as through Google Scholar) or journal articles found online are **not** considered internet references. Avoid using regular search engines; at minimum, replace your traditional internet search with a search of `scholar.google.com`. If the only information relevant and available is from a source that is not peer-reviewed (e.g., a website), but you have the background to be confident in the author, then these sources may be used and cited – this should be a rare occurence, to say the least.

In general, many introductory college courses are not well suited to the type of scientific writing that we will be exploring. That said, in courses with variable outcomes of each experiment, the inquiry approach and nature of the course opens up the possibility of writing our papers in the journal article style. It should be mentioned, however, that the scholarly papers that you will be writing will, clearly, not have the same scope or depth as articles that are found in actual scientific journals. After all, those studies took significantly longer to execute and, likely, levereaged substantially more resources.

1.3 To whom are we writing?

To write an effective scholarly paper it is crucial to first know 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 potential audiences of a scientific work are, in order from most knowledgeable to least:

- *Experts*: these are people with expert knowledge of the same general field of science as you (i.e., chemistry, biology, physics, bioinformatics, etc.) and who possess advanced knowledge of the specific sub-discipline (such as metallobiochemistry, nanotechnology, computational chemistry, etc.). Journal articles and communications are generally written for this audience.

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

- *Student* (or *novice*): this is you. Writing for a student audience is designed to instruct individuals starting out in a field. Textbooks, lab manuals, academic lectures, and many online videos are good examples of communication with a student audience in mind.

- *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. Press releases, popular science articles, and position papers 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 sufficient detail in the prose of the paper. 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. Experts have a better honed metacognitive sense, meaning that they are more likely to know when they don't have the information they need to understand something. As a result, when writing papers for expert and scientific audiences, most of the detailed explanations of prior outcomes are omitted, and relevant references (with citations) are made to other studies and sources. Should the reader have interest or need, they will visit those previously-published articles to get the background that they need. Finding the correct balance of information to present for your desired audience is one of the more nuanced parts of scientific writing.

Similarly, the emphasis on the motivation is likely to change for different audiences. For example, a general audience is unlikely to care about a new experimental approach that would be very exciting to other scientists; instead, big ideas and takeaway messages tend to be the focus of these papers. It is important to understand the perspective of the reader before starting to craft a paper.

1.3.1 Writing for introductory college courses

Most of the technical writing that students in college produce is not genuine scientific communication. The writing that takes place in most college courses is about one thing: a grade. That is unfortunate, because it often leads to poorly executed writing. The best thing that you can do in these circumstances is to ignore the extrinsic motivation of course credit and focus on delivering a polished and meaningful paper. There are three 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.

First, the audience of most course writing are the instructors and graders who 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 work, you may feel that all you need to do is convince a familiar audience that you have properly performed an experiment that they designed. Your goal, however, should be to develop an understanding of writing as it actually happens in the sciences. Thus, you should 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 that you will likely do will be for the *scientific* and *expert* audiences.

Second, 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.

Finally, you instructors will likely provide you with limitations and guidance – hopefully, even a rubric against which they will evaluate your work. Use those guidelines to focus your work and make sure that you are producing your work at the level and depth that are expected.

1.4 Moving from the student to scientist mindset

1.4.1 Writing doesn't just mean writing

While it can be easy to think of writing as the act of putting pen to paper, or fingers to keyboard keys, the writing process is preceded by analysis and research effort. In the case of scientific writing, it is necessary that you first analyze the data that are recorded from an experiment before anything else. After all, without thoroughly understanding what you have achieved experimentally, how can you begin to think about communicating those results with others?

The second step in the writing process is to learn as much as you can about the relevant principles underlying your work and previous studies on the subjects relevant to your experiments. Only after you have done sufficient research, and have developed a thorough understanding of your results, can you then settle on the main claims that you will communicate and the argument that you will make. Outlining that argument prior to writing is critical to executing a cogent and organized paper.

The process of going from fully-analyzed experimental results to a written paper is the main objective of the first part of this guide. Our goal is to develop all of the necessary skills, ubiquitous to all genres of communication in science and engineering, necessary to go from performing experiments to writing papers.

1.4.2 Adopting a scientific voice in writing

Students new to science, and science writing, almost always make the same mistakes when it comes to writing in a scientific voice. As they begin to delve into the world of science, novices reading scientific papers, 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. As a result, novice science writers have a tendency to employ unnecessarily complex vocabulary and sentence composition, in an attempt to mimic what they are experiencing as they read.

In reality, however, scientists strive to communicate about their findings in the most concise, precise, and simple language possible. Given that the concepts about which they are writing are already deep and complicated, they work hard to make sure that the papers are as clear and straightforward as possible.

After all, the goal of all communication – including scientific papers – is to transmit knowledge to an audience and make claims that will be understood and accepted. Writing in a manner that obfuscates the point of the paper is counterproductive to their goals.

The most effective approach to developing and honing a scientific voice is to read more science. For coursework, that might mean reading the papers assigned as background to your experiments. If you haven't been assigned papers to read, consider asking your instructors for some good exemplar papers from which to start. For research, your mentor will likely have a set of seminal papers in the field from which you you can start. In either case, look for phraseology and language that is commonly employed in the field, and try to mimic them in your own writing. Of course, be careful to never plagiarize from other sources. More on reading scientific papers is discussed in chapters 3 and 4.

1.4.3 How many references do I need?

Another challenge for novice science writers is the need to change how we think about the purpose of experimentation and inquiry. Novices in science tend to think of the purpose of labs as "to get the right answer" or "to properly replicate someone's work." As a result, lab reports tend to be thought of as the vehicle for "this is what I got" (presenting raw data or numerical results) or "I got the right/wrong answer because ..." Journal articles, on the other hand, are about "I did this research and this is my best understanding of why I got what I got. These results do (do not) make sense in light of ..." The bottom line is that numbers and tables are not answers; rather, writing strong scientific papers requires one to develop the ability to *research* and explain the science.

Consequently, most students find that they have to change how they think about *sources* and *references*. The biggest mistake made by novice scientists is deciding on the meaning of their data even before they've done their research and analyzed their results. This practice often leads to a very weak paper because these students will write their entire paper before ever engaging outside sources (if ever). To prepare a paper that makes a strong argument, it is necessary to do enough research in the literature to develop a thorough understanding of the chemistry behind the experiment, and to use that knowledge when analyzing the data and explaining the results.

1.4.4 Objectives versus motivation

Before we start down the path to writing a scholarly paper, we must first clarify the purposes behind what we are doing. For some students, it can be very difficult to correctly differentiate between the different levels of motivation and objectives in their experiments. Consider the following different goals:

- 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. For the sake of argument we'll also assume that the student's motivation is not simply to get an A; rather, that the student is interested in learning about science.

- Lab *objectives*: these are the practical items that must be accomplished in the lab (create a standard curve, run a gel, etc.). Some researchers have the practice of writing these goals explicitly in their laboratory research notebooks, and they serve as the focus of the practical performance of the experiment.

- *Motivation*: the over-arching goal of the science that is being studied. Rarely, if ever, will this be given by the instructor. 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.

Before we can talk about *argument* (chapter 5), we need to realize that the only thing relevant to a scholarly paper is the motivation, not the educational purpose or even the lab objectives. The beliefs and claims that we will communicate in our papers will have value because they are inspired and driven by some intrinsic scientific motivation. Take a look at examples 1.1 and 1.2 to see how these elements are different.

Example 1.1: Motivation example 1

Let's consider an experiment in which the size of a molecule is determined by preparing a monomolecular film of stearic acid at a water interface and analyze it on the three levels mentioned above.

- *Educational purpose*: the main educational motives behind this lab might have been for the students to gain basic lab skill proficiency (pipettes, balances), learn about calibration (uncertainty, error), practice basic statistics (mean, standard deviation), gain confidence in the lab environment, and develop skills working problems with unit conversions and dimensional analysis.
- *Lab objectives*: the two major objectives in the lab were to calibrate a micropipette and to find the mass of stearic acid needed to make the monomolecular film using the calibrated pipette.
- *Motivation*: very little was discussed about why determining the size of molecule is so important to study. In fact, there are many possible correct answers, and it is up to you to determine one or more.

Example 1.2: Motivation example 2

Let's consider an experiment in which you determine the effect of sugar type on rate of fermentation.

- *Educational purpose*: the main educational motives behind this lab are for students to identify similarities between photosynthesis and fermentation, understand how to use basic lab equipment in the biology lab, understand how to manage one's time in a fast-moving experiment.
- *Lab objectives*: the two major objectives in the lab were to understand significant figures in data collection and to find the volume of gas produced when yeast is given different sugars.
- *Motivation*: as in the above example, very little was discussed about why we would care about the different sugars that yeast could use as a substrate for the metabolic process of fermentation. This is up to you to do some research to understand the broad application of this experiment.

1.4.5 Difference between Data, Results, and Argument

As we continue discussing scientific writing some terms will keep repeating themselves: Data, Results, and Argument. In the context of the scientific process, *Data* are the facts that will be collected in the experimental setting and will be computed based on experimental measurements and previous results in published studies. In other words, data are facts about the physical world. *Results*, on the other hand, are the outcomes or consequences of the data. Most experiments involve recording substantial amounts of data, but frequently yield only select few results. Finally, the ultimate outcome of doing science is to prepare and disseminate an *Argument* based on your findings and the research that you've done. In this context, your argument is the persuasive exposition that you will make, based on your results and a thorough understanding of the principles guiding the science, in order to convince your readers of your newly held beliefs. Examples 1.3 and 1.4 continue the previous examples by taking a look at the data, results, and argument.

The process of doing science begins with observations and culminates with delivering a strong argument. It is this argument that will take its place in the overall scientific discourse. We will discuss the components of logical arguments, and how to organize them, starting in chapter 5.

Example 1.3: Continuing motivation example 1

Continuing with our example (1.1) of the determination of molecular size, consider the following breakdown:

- *Data*: volume measurements, concentrations, and surface areas are just some of the data recorded in this experiment. None of these would likely appear anywhere in a paper written about the experiment.
- *Results*: the computed surface area of the molecule (with uncertainty) **and** how it compares to other similarly recorded values are the results.
- *Argument*: it is impossible to decide on an argument without knowing the results. The goal of scientific communication is to argue new beliefs based on the experimental outcome(s) that have *never before been observed*.

Example 1.4: Continuing motivation example 2

Continuing with our example (1.2) of the determination of fermentation rates with different sugars:

- *Data*: sugar types and amounts of each, gas volumes for each group, amount of yeast. These are important information that someone would need in order to replicate the experiment. However, the fact that you recorded your data with a #2 pencil is not important.
- *Results*: the average gas volume produced (along with a measure of variance, such as the standard deviation)
- *Argument*: You must know (and understand!) your results before you can determine your argument. See the description in example 1.3.

1.4.6 Contrasting Chemistry and Biology examples

Close inspection of the worked examples in this chapter will highlight an important principle guiding this book: there are very few meaningful differences between writing in the different scientific disciplines. In most cases, any discipline-specific nuances will be beyond the scope of an introductory guide to writing in science; rather, these stylistic choices will be something that you will explore as you **read** more discipline-specific papers and become an expert practitioner in your field.

For the remainder of this guide, the examples highlighted will be either from chemistry or biology. We encourage you to look past the discipline-specific *content*, and examine them for the discipline-agnostic *context* for which they are being brought. On occasion – where significant differences between the fields are found – examples from each discipline will be given, along with explanations of the choices behind them.

1.5 End-of-chapter assignment

1. In your own words, *briefly* list the differences between journal articles (i.e., scholarly papers) and lab reports.
2. For which audience do you believe it would be easiest to write? Most difficult to write? Explain, including a good reason for each of your choices.

3. Scientific writing is all about presenting a strong, cogent argument.
   (a) How can the choice of sources used (and cited) in preparing a paper affect (positively or negatively) the strength of the argument made? Explain briefly.
   (b) Why is it important to ascertain the *Results* and *Motivations* behind an experiment before conceiving the argument that you intend to use when writing your paper? Explain briefly.
   (c) How does understanding your intended audience affect the strength of your argument? Explain briefly.
4. Consider one of the labs that you recently completed:
   (a) Provide an analysis of the *Educational purpose*, *Lab objectives*, and *Motivation* of the experiment.
   (b) What *Data* did you collect? What are the *Results*?

CHAPTER 2

PREPARING APPROPRIATE EXHIBITS

2.1 Exhibits – the start of developing a good argument

All writing is about making an argument – a dynamic form of rhetoric designed to answer questions and pose new ones. In scientific papers, these arguments serve as a mode of disseminating the results of a number of 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. 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 – that will be the subject of later chapters – we must first figure out what our results mean and format them as *Exhibits* that would be useful for making a persuasive argument. Exhibits are visuals for some of the items in your paper that you are offering for explanation, analysis, or interpretation. Exhibits are the grounds on which you will base the argument that you intend to make. As such, they are the first things that we prepare after finishing an experiment and will have a large impact on guiding your argument.

In scientific papers, the exhibits will either be brought as part of the background material or they will be used to present the results of the experiment. In the sciences, exhibits will often be presented as *figures*, *tables*, or *equations*. 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.

2.1.1 Choosing the appropriate exhibit: tables and figures

If you've ever worried about how to successfully convince someone of your point of view, you know that it is important to consider both what you will say and how you will say it. Choosing the points that you want to make, and the depth to which you expound on them, is extremely important. Say too much and you will lose your audience; say too little and you won't be convincing.

It is rarely appropriate to include all of the data that you collect in your experiment. One of the earliest challenges that a scientist faces is knowing what data to present – this is a topic that we will return to in later chapters. For now, we will focus on the equally-relevant task of how to present the data that we've decided is important.

It can be tricky to know how and when to use a table or a figure. Remember, the goal is not to present large data sets – large data sets are included in Supporting Information sections or online repositories accessible to others; rather, our objective is to prepare an exhibit that will convey a *specific and detailed message* to the reader to support your argument. In that way, exhibits become efficient vehicles of information and persuasion.

In general, the type of exhibit you choose depends on the data set that you have to communicate and your expected goals. **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, specific values of your measurements. Tables are most effective when seeing the details of the values will help to convince the reader of some point you will make. Alternately, tables are the appropriate choice when it is necessary to present each value for future reference. **Figures**, specifically graphs, are used to visualize the trend of your data or the relationship between different sets of data. In this way, figures have the ability to communicate concepts in far more efficient way than a table or prose.

In addition to the type of exhibit, you will need to decide how many figures or tables you intend to use. In general, a figure is used to communicate one or two general ideas or trends; conversely, tables can sometimes be used to arrange, present, and contrast vast amounts of data. The best criterion for determining if a table or figure is needed is your overall goals. If a figure or table adds to your readers' understanding, then it is necessary.

2.2 General formatting guidelines for exhibits

2.2.1 Numbering

Figures, Tables, and Equations, are all numbered sequentially (three separate sequences) in a scholarly paper. 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. Tables, Figures, and Equations do not "stand alone" in scientific papers; rather, they are exhibits that support the prose, but do not replace appropriate discussion. To aid the reader in moving between the written discussion and the exhibits, reference statements direct the reader to the appropriate exhibit.

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 using bold font for the label (e.g., **Table 1**). Good reference statements in the text include the label of the exhibit: "Table 3 shows the volume of water at various temperatures" or "The molecular structures of the products are depicted in Figure 12." Exhibits can also be referenced parenthetically, such as "community diversity decreases as pH decreases (Figure 1)." Never use directional words, such as "below" or "above," to describe the location of Tables and Figures, as editors may move the actual exhibits.

One caution: you may notice that in books or other chapter-based documents (e.g., a thesis), exhibits are numbered by the chapter (1.1, 1.2, etc.). In papers, however, this type of numbering is not appropriate.

2.2.2 Proper titles and captions

Every Exhibit must have an appropriate title located above a table and below a figure. The title gives enough information about the exhibit such that, in the context of your paper, an outside reader can understand what the exhibit is showing. An example of a Table title might be: "'**Table 1**: volume of 1.0 g of solvents at various temperatures."

> **Excel does not generate appropriate titles**
>
> Figures do not have titles above them. The standard title that Microsoft Excel generates is not appropriate for our purposes in both format (above the figure, large, and centered) and content. This title is a default Excel setting and should not be included in a scientific figure.

In figures, a title is followed by a **caption**. A good caption elaborates on the information contained within the figure or table, and it tells you everything that you need to know in order to interpret the figure and get the take-away message. Generally, a caption should be a few sentences long and follow the title. Captions should thoroughly discuss the results and messages that are evident in the table or figure, and that will be elaborated upon in the results section. The purpose of the caption is to explain the figure and give context. The title should describe to the reader what is being presented, while the caption should tell the reader any pertinent information that would be needed to interpret the data being presented. In the case of a figure with multiple lines and no legend, the caption should also serve as the legend. For example, "The trend before reaction (solid line) and after the reaction (dashed line)..." If relevant, do not forget to include descriptive information about the data presented (i.e., relevant statistics, parameters, or species).

Captions are single-spaced (even in a double-spaced document) and have a smaller font size than the body text. In this way, it is clear what is a caption and what is text of the paper.

Grouping figure and caption in your document

Word processing packages typically have the ability to "group" non-text elements together for ease of manipulation. Consider entering the caption for figures in a text box (with no outline) and grouping it with the figure. That way, you can easily move the entire figure, with its caption, around in your document.

It can be tempting to think of figure captions as just a label, often relegating them to an afterthought. In reality, however, these captions are extremely important and contain a robust amount of information. The goal of a caption is to make an exhibit stand alone, as frequently readers will glance at figures without reading the entire paper. While we certainly want the reader to read the whole paper, the exhibit and caption should deliver its own self-contained message. Hopefully, your excellent exhibits might inspire them to read more.

To that end, an effective caption will tell the reader exactly what they are looking at, guide them on how to read and understand the figure, and draw conclusions about the implications of the figure. Look at some of the figures, specifically their captions, in your general chemistry or biology textbook. Does the level of detail surprise you?

Some tables only have titles

Depending on the journal, Tables may only have a title and no caption. If this is the case, and additional information needs to be presented, a special character is placed in the table title (e.g., an asterisk (∗) or dagger (†)) and the note is placed below the table in a smaller font that is still noticeable.

2.2.3 Placement in the document

It is best to try to place your table or figure *close* to the text that refers to it, usually at the top or bottom of a page or column. However, it is more essential that the exhibit be formatted properly rather than forcing it to be located in a specific place. Editors have a habit of moving figures and tables to wherever they deem appropriate, though they do keep them in order. Fortunately, since all figures and tables are referred to in the text by number, it is not critical that they be placed on the same page as the referring text.

Make sure that your exhibits are an appropriate size. If you have multiple related figures, it can be very effective to group them into a single multi-pane figure with each sub-figure labeled (a, b, etc.). When referencing a part of a multi-pane figure, mention the figure number and letter (e.g., "in figure 3(a)").

Equations, on the other hand, are always located immediately before or after the text that first describes them, as they are part of the prose and discussion. If an equation is mentioned again later in the paper it is referenced, but not repeated. Equation numbers appear on the right of the centered equation, aligned with the right edge of the page.

2.3 Preparing effective figures

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

- **Graphs:** graphs are one of the most important 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. Calibration curves, spectral data, and chromatograms are all common graphs found in papers.

- **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. The results of that analysis are presented as a crystal structure.

- **Non-data figures** (or schema): reaction mechanisms, gels, maps of field sites, and illustrations are all types of figures that are critical to understanding a paper, but do not contain numerical data. It may be that you've assembled a custom apparatus for a certain experiment or that you have a lengthy reaction scheme. In either case, a figure will help clarify your work to the readers. To be clear, however, you would not present a graphic representation of common laboratory equipment. Only figures that are important contributors to your argument are necessary to include.

2.3.1 Considerations for preparing appropriate graphs

Software programs that can be used to prepare graphs (such as Excel) are powerful and have many nuanced options. Think carefully about presenting your data, and learn how to use the packages appropriately. In general, the default options may not be the best options. Consider the following when preparing graphs:

- **Which variable goes on which axis:** there is no difference between calling a graph "pH vs. volume" or "volume vs. pH" – in both cases, the volume of base added is on the horizontal (x) axis. In a graph, the independent (manipulated) variable is plotted on the horizontal axis and the dependent (responding) variable is plotted on the vertical axis (y-axis). That said, many do consider it more proper to write about a graph of "the dependent variable (y) as a function of the independent variable (x)."

- **Graph type:** choose the correct type of graph for the type of data you are presenting. Excel's default is the *bar graph*, which can be useful for presenting data to be contrasted but that is not related. For data that show a correlation (whether linear or non-linear), it is appropriate to use an *xy scatter* plot.

  Think closely about your data and how to visually represent the results. 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:* examples of exceptions to the previous rule are chromatograms, spectra, and titration curves. Because these figures are made by taking regular and frequent data points, they are plotted using a smooth line (without markers / points).

- **Axis labels:** all axes need a label and units, unless the graphed quantity is unitless (such as pH or absorbance). There is no need to start the plot at the origin (point 0,0) unless that point is relevant to understanding the data. For instance, if you took a spectrum between 400 and 700 nm, the x-axis range should be 400-700. Also, never add a point at the origin of your graph unless it was actually *measured* in the experiment.

- **Dividing lines:** the default graphs produced by Excel include horizontal and vertical lines at the major tick marks. Rarely would it be appropriate to include gridlines in a graph.
- **Legends:** when plotting many sets of data in a single graph, a legend is critical for helping to differentiate between the sets. That said, legends are only useful if you are plotting more than *one set of data* on the same graph; otherwise, they are a waste of space and can be distracting. Even then, identifying the individual plots can be done in the caption, if there are not too many sets. In practice, a legend is always necessary for graphs that present a large number of data sets (i.e., more than 3), and some people will include a legend for graphs with as few as two distinct data sets (a trendline and a data set are only one set of data).
- **Using space properly:** you can resize the individual components of the graph to maximize the use of the figure within your final document.
- **Color and shapes:** for plots with multiple data sets, it is important to differentiate between the them. Even if you print in color, it is advisable use different symbols for the markers corresponding to different data sets. That said, make sure that data markers are clear and reasonable shapes.
- **Trendlines:** Where appropriate, for showing trends in the data, add a trendline and display its equation on the graph.

2.4 Preparing effective tables

While tables and figures are both useful for showing trends (though figures are much better at this), tables are the preferable exhibit to use when it is important that the actual values be accessible to the reader. That said, just because you are providing data to the reader, it is not license to dump all of your raw data in one place. It is important that your tables have a good balance of being complete, but also as streamlined as possible.

2.4.1 What needs to go into a table

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

Conversely, presenting too much in a table is also a mistake. 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.

2.4.2 Considerations for preparing appropriate tables

Most of table formatting comes down to aesthetics. Consider the following important guidelines for preparing your tables.

- **Header row(s):** all tables have a header row at the top. These headers explain the type of data that will be found in a given column. Units are always included in the header rows, sometimes in the second row. Often, header rows are bolded or shaded so that they are distinguished from the other rows.
- **Breaking up the rows:** do not use gridlines in tables – this is simply not an appropriate style. Do, however, use horizontal lines to create separation between the header row(s) and the data below. Many people find it aesthetically pleasing to also place horizontal lines above and below the table so that it is easily recognizable. Sometimes additional separators can be useful for grouping related rows, cells, or columns.
- **Row spacing:** all rows should be the same height, with the exception of header rows that can be taller than the others.

Example 2.1: Examples of well-executed figures

Consider the following examples of well constructed figures:

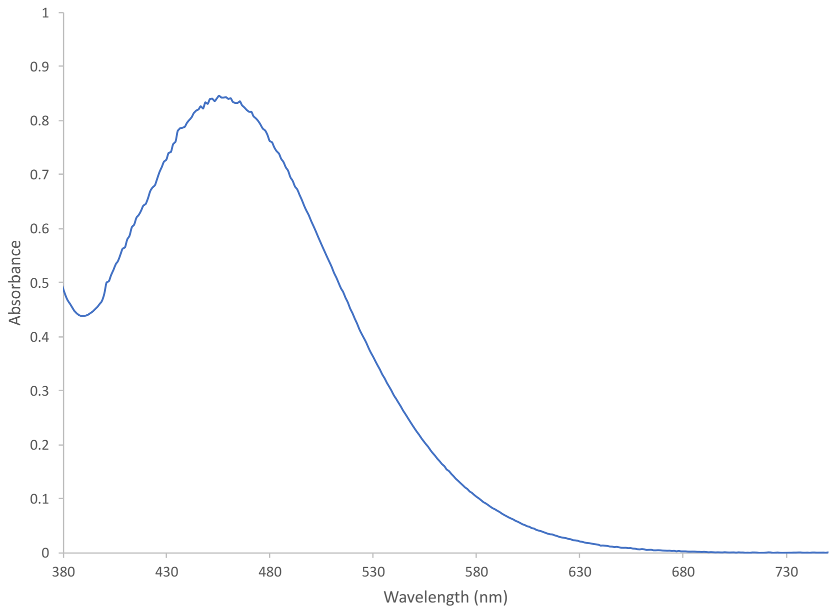


Figure 1: UV-Vis spectrum of carboxyfluorescein in methanol (5×10^{-3} M, 1.00 cm cuvette). The maximum absorbance wavelength, λ_{max}, is located at 455.0 nm.

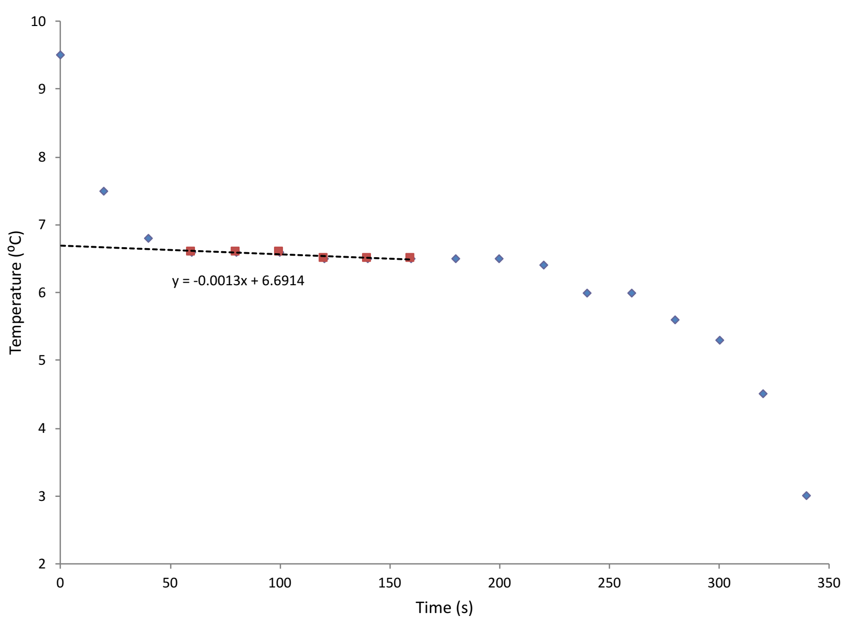


Figure 2: Cryoscopic freezing curve for cyclohexane (K_f = 20.2 kg K/mol). The linear trendline (with equation) is shown for the freezing portion of the curve (between 60 and 160 s), and the extrapolated freezing point is 6.7 °C.

- **Column spacing:** it is desirable that there be uniform space between the data in each column, which means that column widths need to be adjusted to achieve even spacing. Also, it is best to avoid too much white space between the columns.

- **Units and precision:** units are **not** included in the cells with the data. Instead, units are included in the header row. Make sure to choose units that will lead to data that is easy to read in the body of the table. For example, if small mass measurements are being displayed, report the values in milligrams, and report the units (in the header row) as mg or 10^{-3} g.

Example 2.2: Example of a well-executed table

Table 6: Cereal and iron(II) standard addition solutions

Solution #	Volume Cereal Solution (mL)	Volume Standard Fe Solution (mL)	Total Volume (mL)	Average Absorbance
1	10	0	100	0.0012
2	10	1	100	0.0025
3	10	2	100	0.0065
4	10	5	100	0.0125
5	10	10	100	0.0250
6	10	15	100	0.0375
7	10	20	100	0.0500
8	10	25	100	0.0630

2.5 Equations, Chemicals, and Values

2.5.1 Which equations are relevant?

Chemical equations, reactions, and formulas should be included if they are directly relevant to your argument. Relevant chemical equations include those that describe the chemistry you are doing. Mathematical equations should only be used if they are relatively un-common, and are involved with interpreting your data. Usually, the entire derivation of an equation is not necessary, unless the derivation itself is the novel part of the work being presented.

2.5.2 Formatting chemical equations and the names of chemicals

In the sciences it is important that the values, equations, and species be represented properly. For example, in Biology, Latin names (binomial nomenclature) of species are always italicized. Similar rules exist in the physical sciences for equations and values. Consider the following guidelines:

- **Subscripts and superscripts:** make sure to properly format all chemical formulae with appropriate subscripts and superscripts. Writing C2O42− is not acceptable (it should be written as $C_2O_4{}^{2-}$).

- **States of matter in equations:** where relevant, the states of matter need to be included in chemical equations. We write $Cu^{2+}(aq)$, not Cu^{2+}.

- **Symbols:** always use the appropriate symbol for something. Use μ (not u) for micro, $\rightarrow$ for a normal equation arrow, and $\rightleftharpoons$ for equilibrium. Note: $\leftrightarrow$ means resonance and cannot be used in place of equilibrium arrows.

- **Numbering:** while reactions, equations, and math expressions do not need a title or caption, they must have an equation number.

- **Italics:** in equations, only variables and constants are italicized. Letters representing atoms should never be italicized. Carbon dioxide is written as $\mathrm{CO_2}$, not CO_2.
- **Capitalization:** in prose, chemicals are typically identified by name, not symbols. Chemicals are **not** proper names. This means that the names of chemicals are not capitalized (HCl is hydrochloric acid, not Hydrochloric Acid). Sometimes, authors use bold numbers to refer to structures from schema and mechanisms.

2.5.3 Values and units

Given their tremendous importance in scientific communication, it is very important that values be presented in an appropriate way. Consider the following:

- **Units:** all measurements and values include a number and a unit. Always include a space between the number and the unit. We write 10.5 m, not 10.5m.
- **Leading zero:** numbers less than 1.0 must be reported with a zero preceding the decimal point (i.e., as 0.123, not .123). The decimal point and the digits that follow it are called a mantissa, not a number.
- **Precision:** values should be presented in a clear way that shows how precisely the number is known. For a value with a known uncertainty, this means only using the appropriate significant figures in both the value and the uncertainty. The same applies to statistical values.
- **Scientific notation:** numbers written in scientific notation are always written with $\times 10$ (not the "E" or "e" that is the remnant of programming languages like Fortran and seen in Excel).

Importance of exhibit formatting

The most important aspect of technical writing are the evidence and concepts brought to support your claims. While the formatting of exhibits does not directly affect the argument you are making, when exhibits are formatted appropriately they are substantially more persuasive.

Gallery of tables and figures

A gallery of some good examples of tables and figures from published articles across the scientific disciplines can be found at:

`http://people.bu.edu/abramsb/research/other/figures-tables.html`

2.6 End-of-chapter assignment

1. Look at Examples 2.3-2.7 (in the pages that follow) and explain the differences between the Correct and Incorrect versions of the Tables, Equations, and Graphs. What is the main point of each exhibit (i.e., what role does it play)?
2. Figure captions are necessary for making figures 'stand alone.' Explain how lack of detail in captions negatively impacts the argument made in the paper.
3. We won't be writing the traditional 'lab reports' (see Chapter 1 for differences between lab reports and scholarly papers). How might the amount and type of data included in a table be different in a lab report versus a scholarly paper?

4. Consider a recent lab that required the preparation of at least one table. Prepare an appropriate table using the information in this chapter. Don't forget to include a title for your table.

5. Consider a recent lab (or multiple labs) and prepare two appropriate figures: one spectrum/continuous and one calibration curve/trendline graph. Make sure to include detailed, well-written captions for your figures, so that the reader will understand the main take-away point of the exhibit without further explanation.

Example 2.3: End-of-chapter problem 1 (Tables)

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 - 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 is more clear? Can you spot all of the difference between the two versions? Note that this is just one way to properly format a table.

Example 2.4: End-of-chapter problem 2 (Equation)

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

Correct:

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

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

Example 2.5: End-of-chapter problem 3 (Values)

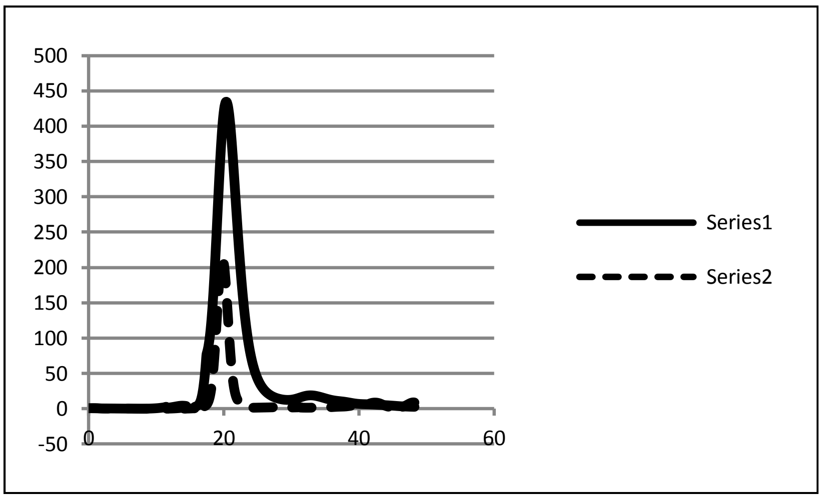
Incorrect: $\varepsilon = 18713.45 cm^{-1}M^{-1} \pm 518.3 cm^{-1}M^{-1}$

Correct: $\varepsilon = (1.87_1 \pm 0.05_1) \times 10^4\ \mathrm{cm^{-1}M^{-1}}$

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

Example 2.6: End-of-chapter problem 4 (Graphs – chromatograms)

Incorrect:



Correct:

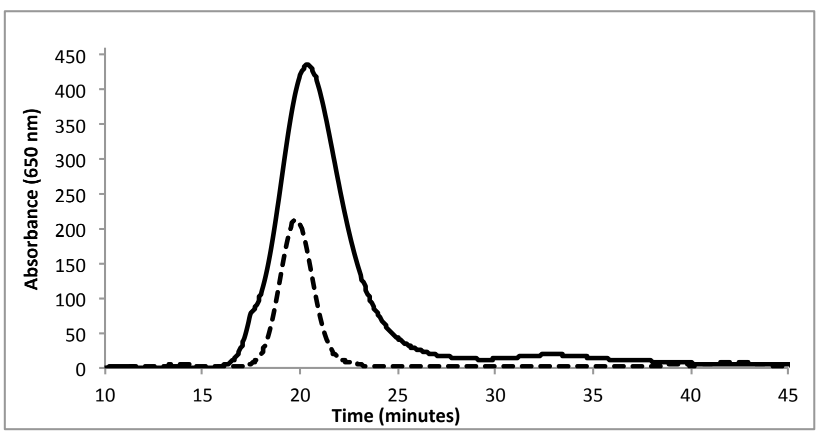
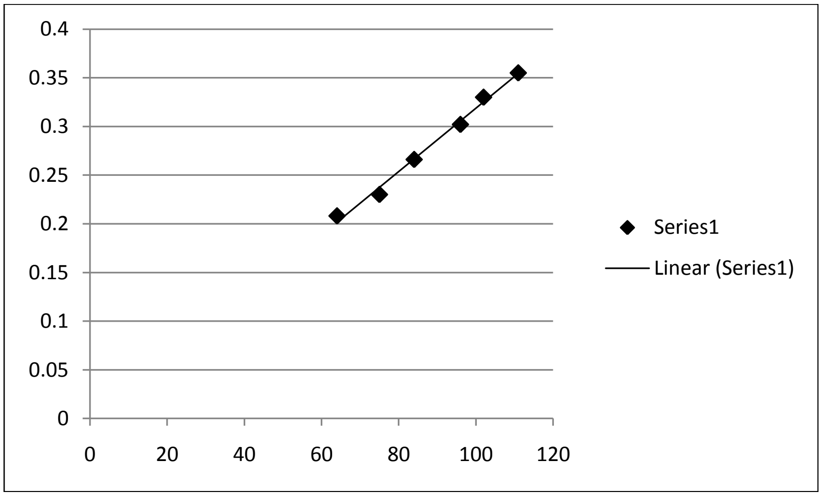


Figure 3 - HPLC Chromatograms of chocolate content remaining in socks after being washed with Washing Machine 1 (solid line) and Washing Machine 2 (dashed line). All absorbances were recorded at 650 nm. The retention times for both machines are between 20 and 22 minutes.

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 2.7: End-of-chapter problem 5 (Graphs – calibration curve)

Incorrect:



Correct:

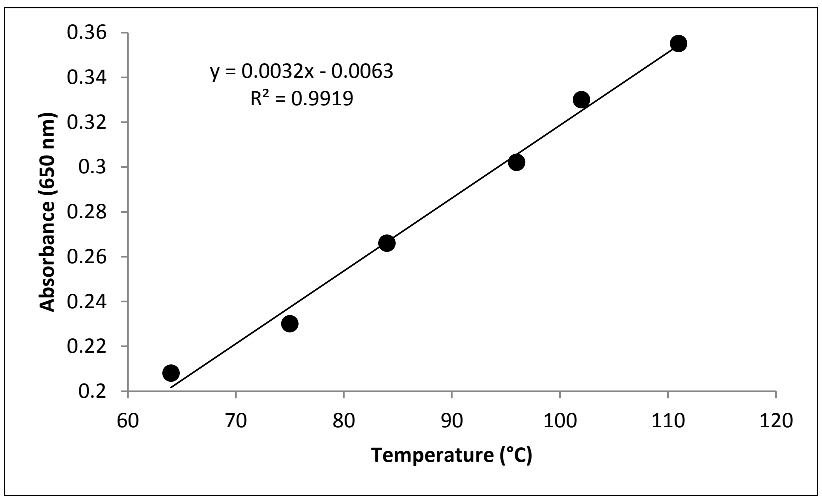


Figure 7 - Temperature dependance on washing machine efficiency. Peak absorbance at the maximum wavelength, 650 nm, is plotted against the temperature of washing.

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

CHAPTER 3

READING AND REFERENCING SCIENTIFIC PAPERS

It is estimated that there have been over 50 million journal articles published since the inception of modern science (i.e., the late 17th century). Today, there are more than 30,000 journals, most of which can be accessed online, and nearly two million articles will be published this year. To say that it can be daunting to find relevant information in that vast sea of knowledge is certainly an understatement.

That being said, the process of scientific discovery is inextricably dependent on the discoveries of past scholars and contemporaries. The sentiment is most famously captured by a statement made in Newton's letter to Robert Hooke: "If I have seen further it is by standing on the shoulders of Giants." All of our progress is based on the works of great researchers that precede us, the tutelage of our teachers and mentors, and close collaboration with our peers. All of that is to say, that in order to be successful in our scientific pursuits, we must have the skills and dedication to finding the information provided for us in the published works of others.

Chapters 3 and 4 of this guide are dedicated to skills and approaches for engaging with previously published studies. In this chapter we will focus on three major goals: (1) methods for the purposeful reading of papers; (2) collecting and cataloging sources of interest and potential utility; and (3) how to appropriately acknowledge the sources in our work.

3.1 How to read scientific papers

There are a number of good reasons why you would likely be reading a scientific paper. Among them are: gathering specific data, researching the current state-of-the-art in a field, preparing for a 'journal club,' and keeping up with the literature in your field.

How you approach reading a paper is very dependent on what you hope to accomplish – a partial list is presented in Table 3.1.

Table 3.1: Common goals for reading scientific papers

Goal	Primarily-relevant sections
Learning new method / approach	Methods, Introduction
Understanding limitations of a method	Conclusion, Discussion
Significance of a research area	Introduction, Conclusion
Looking up data / values	Results, Figures
Broad interest in the field	Abstract, Conclusion

To help illustrate, let's examine a couple of approaches that experts have found to be helpful when reading research papers. Using either of these methods, you should be able to extract the gist of the argument from a scientific paper using a quick scan – only a few minutes. In order to learn the material well, you will likely need to spend more time working through the authors' data and claims, and taking substantial notes.

You will find it useful to make **detailed annotations** on the papers that you are reading. Additionally, many digital reference managers will allow you to save an annotated copy of the paper. Most of these programs can even assign keywords to the papers so that you can easily search for the concepts that you want to find at a later time. Keep in mind, when scientists say "read a paper," they really mean digest and annotate a paper.

When you know a paper will be helpful

First, take a look at the exhibits that the authors have chosen to show within the paper. Ask yourself: (a) What reactions are being shown in the exhibits (schema, figures, etc.)? At first glance, do you understand these schemes? (b) What structures are they choosing to show? Why?

Next, try to very generally interpret what the authors are showing in the exhibits (figures, tables, equations, etc.) in the paper (e.g., kinetic data from UV-vis, redox potentials from electrochemistry, molecular structures from x-ray crystallography, etc.) This can usually be done by inspecting the axes and the captions.

Third, read the conclusion of the paper. The conclusion is a very short and succinct section that conveys the overall findings of the article and, typically, what the authors believe is most significant. If there is no separate conclusion section, read the last two paragraphs of the discussion.

Finally, read the abstract (if there is one), because this gives a general overview of the findings in the paper. If the goal is to understand the paper, then you are likely done. If, however, your goal is to present the paper to others, then read through the paper fully and take notes on each area of interest.

Now let's say that you have conducted several searches and have a long list of possible papers to use, but are unsure which will be helpful.

When you have a long list of possible references

Start by skimming through the figures and read the captions to make sure their data match their objectives indicated in the abstract. At this point, try to interpret the data without authors' narrative (i.e., don't read their conclusions).

Look at the bold headings in the methods section to determine whether or not you are familiar with their techniques. If there are techniques that you don't recognize, use a search engine to gather background information.

Read the last paragraph or two of the introduction to learn about their motivation, objectives, and findings (argument summary). For in-depth understanding of the paper (i.e., journal club presentation), read through the results and discussion section and go back to the figures to confirm authors' arguments.

For more information and details, there are a number of excellent articles on how to read scientific papers:
`https://www.huffpost.com/entry/how-to-read-and-understand-a-scientific-paper_b_5501628`
`https://www.sciencemag.org/careers/2016/03/how-seriously-read-scientific-paper`
`https://www.elsevier.com/connect/infographic-how-to-read-a-scientific-paper`

3.2 Working with references in your scientific papers

Journal articles, letters, and research proposals all contain a References section that lists articles from the primary and secondary literature that were used in the preparation of new work. A proper References section includes scientific sources that are relevant, respected, and current; more importantly, it contains the actual sources used in the research for the paper.

3.2.1 Why is citing the literature necessary?

All scientific progress, in general, is an extension of work done previously. Early scientists documented and kept track of each other's contributions. When any new discovery was made, they responded by "referring" to what was already known about a particular topic and where, when, and by whom it was published. Today, we continue this practice by appending a References section to our own work. In this section, we cite a piece of original research or major contribution to the field. By "referring" to a body of work, we acknowledge pioneering work in a field, assign credit for a particular intellectual discovery to an individual or group, supply a source of additional reading on a topic, provide a historical perspective and/or context to any new work, and ensure high ethical standards in science.

Using references also allows you to keep your writing more concise. In that way, a reader who is familiar with a topic isn't burdened with detailed explanations of background that should be well-known, but someone who isn't well versed knows exactly where to go to find the information.

Understanding the contributions that others have made to the field is critically important as a young scientist. As you begin to read the scientific literature, pay close attention to not only the content of the text, but also to the list of references included therein. After all, a common complaint in peer review is an inadequate understanding of the scientific literature and could cost you publication.

3.2.2 What needs a reference?

We will explain how to format references within a text and in the References section itself later, but first you may be wondering when to use references and how frequently they are needed. In general, when you are writing any type of scientific communication, references must appear for any idea that you cannot claim as uniquely your own. That means that you need to provide references for things like:

- Procedures: that you followed, or even borrowed from, in the process of doing your work. For example, students following a procedure from a guide (like a lab manual or journal) for doing iron-content analysis would need to reference the guide.
- Concepts: especially when it comes to novices, there will be a lot of references to books, articles, and reviews, that explain fundamental concepts that are needed for understanding the work (both its motivation, the methods used, and the outcomes).
- Other studies: science doesn't happen in a vacuum – we will often be doing work to extend, refute, support, or refine previous work. Those studies must be cited.

While citations should appear for any source that has been influential for the present study, an exhaustive list of references is not always necessary. For instance, suppose that you are reading a journal article that references three others; even though all four sources were used, you may choose to only cite the one, lead reference.

Finally, information that is commonly accepted knowledge does not require a reference. It can be difficult to know where to draw the line when it comes to this supposed 'common' knowledge. For now, let us assume that anything that you needed to research is not common.

References in a Journal Article

Since most of this guide is devoted to learning about writing journal articles, let's investigate the nature of references by section of the journal article.

- **Title and Abstract:** no references appear in these sections.
- **Introduction:** the introduction of a scientific paper includes the motivation for the study and a thorough review of the state of the art of the field (i.e. background information). Both of these areas will involve substantial references to the literature.

- **Results and Discussion:** while the results of your experiment will likely not require citation, the discussion will usually be very heavily cited. Make sure to include all of the sources that you referenced when analyzing and interpreting your results, the sources of all previously-referenced results and values, and anything you used for drawing conclusions. Strong arguments will be those that are rooted in thorough research.
- **Conclusion:** citations are common when discussing any future directions, or extensions, to the work. Additionally, the global ramifications of your work are usually based on research as well.

3.3 Format of citations and references (in chemistry)

Citing references within the text will largely depend on the editorial conventions of the particular publication. Most of the chemistry journals, as well as the papers that you write as a student in a chemistry course, follow the standards from the flagship chemistry journal of the American Chemical Society (The Journal of the American Chemical Society, commonly referred to as JACS). The complete details of the style and formatting can be found in the ACS Style Guide, but here are the most important rules to follow when using references within the text:

- References are numbered chronologically starting at the beginning of the document, including those in tables, figures, and graphs. Don't forget to check your references if you switch sentences around. When a source is cited more than once, the numbering follows its first instance.
- Citations in chemistry use Arabic numerals (1, 2, 3) only.
- A superscript should appear immediately after an idea requiring a reference has been first introduced. If the reference applies to an entire sentence/clause, the superscript will appear *after* punctuation.

> **Example 3.1: Superscripts for citations**
>
> Phenolphthalein has been used extensively as a pH indicator in titrations.[1]

- Author last names may appear in the text when referring to particularly noteworthy work. If a reference has two authors, both authors' last names should appear separated by the word *and*. If a reference has more than two authors, the corresponding author (usually the principal investigator) should be listed, followed by the phrases *et al.*, *and coworkers*, or *and colleagues*.

> **Example 3.2: Referencing authors by name**
>
> A working electrode was made from platinum as reported by Haddon and Loria.[2] A reference electrode was constructed from Ag/AgCl as described by Jenkins *et al.*[3]

- If you cite two references for a single idea or item, superscripts should appear consecutively with a comma, but without a space. If more than two references are cited, a range should appear (ascending and using an en dash).

> **Example 3.3: Multiple references**
>
> Palladium-mediated reactions are particularly important for C-N bond formation.[4,5] Olefin metathesis catalysts have revolutionized pharmaceutical C-C bond formation.[6–8,10]

- A reference should be cited at a reasonable point in a sentence or clause.

Example 3.4: Location of citation

... recent studies suggest[4] ... was reported[1,3–5,7] ... as described[14–16] ... previous results indicate.[3,4]

3.3.1 Format of the References section of your paper

The references section, located immediately following the Discussion/Conclusion section of a paper, is where the information on all the references are listed that correspond to in-text citations. This makes it easier to find references on a particular topic or from a particular author since only the most important information is included in a citation. Just as mentioned above for the in-text citations, you will use the JACS formatting criteria. Here, we will go through the conventions that you will apply to your own references section.

A References section at the end of a document should list the references in chronological order as they appear in the text, with numbers. Depending on the source, there are a few key criteria that are required to ensure proper referencing. The following list shows you how to properly cite a particular source in the References Section:

- **Book (no editor)**: Author 1; Author 2; Author 3; *Book Title*, Edition Number (if any); Series Information (if any); Publisher: Place of Publication, Year; Volume Number, Pagination

  Example 3.5: Referencing a book (no editor)

  Grossman, R. B.; *The Art of Writing Reasonable Organic Reaction Mechanisms*, 2nd Ed.; Springer-Verlag New York, Inc.: New York, 2003; pp 23-25.

- **Book (with editor)**: Author 1; Author 2; etc. Chapter Title. *In Book Title*, Edition Number; Editor 1, Editor 2, etc., Eds. Series Information (if any); Publisher: Place of Publication, Year; Volume Number, Pagination.

  Example 3.6: Referencing a book (with editor)

  Paolesse, R.; Monti, D.; Dini, F.; Di Natale, C. Fluorescence Based Sensor Arrays. In *Topics in Current Chemistry: Luminescence Applied in Sensor Science*; Prodi, L; Montalti, M; Zaccheroni, N, Eds. Springer-Verlag: Heidelberg, 2011; 301, 139-174.

- **Journal article**: Author 1; Author 2; etc. *Journal Abbreviation*, **Year**, *Volume* (Issue, if any), Inclusive Pagination.

  Example 3.7: Referencing a journal article

  Merrifield, R. B. *J. Am. Chem. Soc.* **1963**, *85* (14), 2149-2154.

  Note: list all authors (if fewer than 15). Use the appropriate journal abbreviation from the Chemical Abstracts Service Source Index (CASSI). You can search for the appropriate abbreviation at the following link: `http://goo.gl/q44au`. A brief list can also be found in the ACS Style Guide.

- **Patent**: Patent Owner 1; Patent Owner 2; etc. Title of Patent. Patent Number, Date.

Example 3.8: Referencing a patent

Brewer, A. K.; Knight, J. Pyrrolopyrimidines as Antineoplastic Agents. WO/2011/095246, 2011.

- **Thesis**: Author. Title of Thesis. Level of Thesis, Degree-Granting University, Location of University, Date of Completion.

Example 3.9: Referencing a thesis

Boone, A. C. PNP Ligands in Asymmetric Catalysis. Ph.D. Thesis, University of Notre Dame, South Bend, IN, 2004.

- **Electronic Reference**: Author (if any). Title of Site. URL (accessed Month Day, Year), other identifying information (if any).

Example 3.10: Referencing the internet

Sigma-Aldrich Home Page. http://www.sigmaaldrich.com/united-states.html (accessed July 13, 2011).

On rare occasions, authors may also cite particularly fruitful conversations with peers and mentors in the field. There are two approaches to acknowledging the contributions that other people, not sources, have made to your work. In most cases, substantial contributions are mentioned in the Acknowledgements section at the end of the paper by including a statement like: "the authors are grateful for the insights from conversations with Jane Doe." This attributes some general credit for contributions to the work from that peer.

Alternatively, some cite a particular idea or warrant – like they would cite a paper or book – directly in the text. The line in the References for this type of citation might read: "Conversations with Jane Doe (Boston University, Department of Chemistry)." This approach is quite rare, and you should certainly not be employing it in your undergraduate coursework.

Different approaches to citations and references

As mentioned above, each discipline and journal has its own expectations for how sources will be incorporated and formatted. Another common approach employed is to reference sources by author and year. For example: "Mutants with more than 90% gene homolysis tend to have near identical function (Spilios, 2017)." The specific reference can be identified in the Literature Cited (or References) section, which is typically organized in alphabetical order by the last name of the first author, by looking for the author and the year of publication.

Whatever the style, it is critical that you make sure to adopt the appropriate conventions for the intended journal, otherwise your paper will receive substantial criticism or perhaps even be rejected outright. Details about the appropriate formatting of references is always available on the publisher's website.

3.4 Reference managers

In the past, faculty offices used to be filled with folders upon folders of potentially relevant papers. Beyond the harsh ecological impact of printing so many papers, a substantial challenge was to adopt an effective filing system that would make it as easy as possible to locate a paper of interest should the need arise. Inevitably, a tremendous effort needed to be exerted to find an elusive source that was potentially beneficial.

Reference managers are the filing cabinets of the 21st century. Instead of printing and filing papers physically, scientists can gather their interesting sources – from various media – all in the same place on their computers and the cloud. Examples of these applications include: Mendeley (free, all platforms), Papers for Mac (not free), EndNote, Zotero, and more. The free account for Mendeley or Zotero should more than suffice for the work that you do as a student.

Most of the popular reference managers also give the user the ability to annotate or comment on the sources directly, make notes, add keywords for easy searching, and some can even help you in finding additional related papers that you have not yet read. One of the best advantages of many reference managers, however, is that they can export *properly formatted citations* for your papers in a variety of publisher styles – this will save you tons of time and ensure that your References section is always expertly executed.

CHAPTER 4

FINDING AND COLLECTING AUTHORITATIVE SOURCES

In the previous chapter we discussed working with papers that you have found or been provided. In this chapter, we will turn our focus to finding sources of information that answer our questions and guide our inquiry. The challenge of finding reliable, meaningful, and fruitful information is compounded today by the access provided by the internet. On the one hand, the internet puts the vast collection of human knowledge at our fingertips without the need to travel to libraries. Published articles, books, and other references are available – often with open access – to anyone with a web browser.

On the other hand, the volume of *unreliable*, *unreviewed*, and *misleading* information available on the internet is enormous. For example: while most websites explain the (scientifically correct) value and safety of vaccinations, there exist a large number of websites that seek to confuse readers with pseudo-scientific (at best) and fallacious (at worst) claims about the horrors of vaccinations. What is more concerning is that, for the novice, it can be nearly impossible to discern the difference between the sources that are authoritative and those that are not. While we are not overly concerned that you will fall prey to predatory sources in chemistry, there are a plethora of bad sites out there that are filled with erroneous chemical information and bad heuristics. That is our challenge. One of the most important, transferable skills that you will develop is the ability to locate *reliable* and *relevant* information.

4.1 Tools and strategies for finding relevant papers

4.1.1 Exploring from a lead reference

The easiest way to find interesting new papers is to start with a relevant paper that you already have. This initial paper, from which you will start your exploration, is often called a “lead reference” – the starting point for research on a concept. Start by finding your lead reference online using one of the database tools discussed later in the chapter (SciFinder, Google Scholar, or Web of Knowledge). Once you have reached the website for the paper, notice that these sites offer easy access to a abundance of related content. Many of these sites have easy links to papers that have cited the paper you are looking at, links to the papers cited in the paper, and additional related content. Surfing through these materials can help you find other information that is related and relevant.

Doing research from a lead reference is not necessarily easy, but it is often more expedient and focused than starting from scratch. Often, the challenge of looking for information from scratch is that you either don’t yet know what you want to learn, or you don’t know how to articulate the search parameters in a narrow and productive way. There is an art to finding information. In the next few sections we will discuss approaches to searching for information from scratch.

4.1.2 Searching for sources – common strategies

There are several strategies one can use to perform an effective search of the literature. The type of search will depend on what type of information you need. For example, it might be quicker and easier to perform a regular Google search for *vitamin C* to find out its structure than to spend time logging into SciFinder Scholar. However, if you wanted to know who sells it for the cheapest price, you might use a much different strategy. You will find below several strategies for making the most of your literature search.

- **Keyword/Topic Search:** The most common search for beginning scientists is the keyword or topic search. Because you are unfamiliar with the literature, this can also be the most difficult search to perform. There are two main ways to search by topic, each with their own merits. You may find that by using both strategies, you obtain a more complete set of references than by just using one technique:
  - Start general and become more specific – if your goal is to find introductory-level information on a topic, it is best to start with general search terms. You can then use the filtering capabilities of each program to narrow the large list of references into something more manageable (ie., journal name, author, year, document type, institution, etc.). Refining by topic is also a good way of becoming more specific.
  - Start specific and become more general – if you are looking for information that is specific to a particularly narrow area of research, start by using search terms that describe exactly what you are looking for. If you are unable to generate any hits, make your search terms more general by eliminating words, using broader terminology, and not using any filters.
- **Cited/Citing Reference Search:** SciFinder Scholar, Web of Knowledge, and Google Scholar (more on these tools later) are all good choices for searching for a particular article, references it cites, and references that cite it. However, the databases each program searches are different, so you may find slightly different results. Simply enter the article citation information into each program. Once you find the reference, click on "Get Cited" or "Get Citing" in SciFinder Scholar (similar terms in Web of Knowledge and Google Scholar) to generate a new list of references which you can peruse. Another useful feature of Google Scholar is the link "Related articles" which will lead you to tangentially-related citations.
- **Author Search:** All three search tools are also good choices for searching by author. Simply enter the author name to see which references have been published by a particular author. Be cautious of authors with the same name (this is easy to catch if you are searching within analytical chemistry and retrieve additional hits about evolutionary biology). Also be aware that some publications might have different versions of the same person's name (e.g., J. Harden vs. J. D. Harden vs James D. Harden). SciFinder offers the option to display all results of name variations if they show up.
- **Chemical Structure Search:** Using just those programs introduced to you in this chapter, searching by structure is only possible using SciFinder Scholar. Its user-friendly and intuitive chemical drawing program will enable you to search for chemicals that have been indexed by Chemical Abstracts. Each result is linked to reactions containing it and references for its use, synthesis, or general study. Simply choose "Get Reactions" or "Get References" to explore.
- **Combining Search Tools:** SciFinder Scholar, Web of Knowledge, and Google Scholar each have their own set of strengths and weaknesses. Knowing when to use each of them comes with practice but is important to obtaining the information you need in a reasonable amount of time. Fortunately, the information you glean from one search engine can be used to perform a search in another. SciFinder is really good at finding references on a research topic. Once found, you may search Web of Knowledge for its cited/citing references or search Google Scholar for related articles. Likewise, Web of Knowledge is excellent at performing author searches. But if you wanted to know if a particular author has ever published a synthesis of a particular compound, you would need to follow up with a SciFinder Scholar structure search. Thus, there are many ways to "mix-and-match" search tools to gain maximum coverage of the literature.

- **Other Helpful Hints:** Boolean operators such as AND, OR, and NOT help you filter search results from the beginning and limit the generation of false or misleading hits (all capitals must be used). Wildcards are special characters (such as *) that permit alternative spellings or suffixes to your search terms (for example, the term *electrochem** will return hits that include electrochemistry and electrochemical). In addition, placing a term in quotation marks will ensure that a particular word or phrase appears in your results set exactly as written.

4.1.3 What references are acceptable?

We've already discussed what needs a reference: anything that is not common knowledge and, therefore, required research. But, how do you know which references are good and which ones are not? To be frank, this comes with practice, but you can become better at it by reading the primary literature.

For beginners, there are several criteria that will help you decide which references are acceptable. Consider the following criteria:

- **Type of Source:** For the introduction section of your paper, books and review articles are the best sources of general information on a research topic or experimental method. You may find these citations by refining your search in one of the databases (discussed below) by reference type. Other sections of your paper may require you to cite a specific article and it is standard practice to find more recent papers that cite this lead article as a reference - someone may have recently expanded upon this work. Internet references are rarely acceptable.

Peer Reviewed Sources

The common theme for the sources listed above is that they are **peer reviewed**. This means that they have been vetted by experts in the field and found to be valid, credible, and of sound science.

If you are ever wondering if a source is a valid source to cite, ask yourself if it is peer reviewed. If yes, then go ahead and cite! If no, don't even bother reading it (this is the case for most websites).

- **References within a Source:** An additional supply of leading references may come from the introduction section of a research article on a topic. If the article is recent, then someone has already done the literature searching for you. It is good practice to look up all of the references found in the introduction of a journal article to better understand a topic.
- **Timeframe:** The most current information is probably the best indicator of the state-of-the-art, so you should choose references that have been published in the last 15 years. However, a seminal publication on a topic, often published decades ago, should also be referenced to highlight major contributions to the field. Thus, there is a balance between being up-to-date and respecting the scientific historical record.

4.1.4 What references are *not* acceptable?

There are three major things to avoid in choosing your references: internet references (see below), foreign-language references (we will restrict our sources to English only), and the abstracts/proceedings of meetings or conferences. The major reason to avoid internet references is because of their reliability. Foreign journals and the proceedings/abstracts of meetings are certainly reliable, but you couldn't have possibly used them to glean information. After all, you didn't attend that conference!

An important note about the use of electronic references

There is a difference between an "internet reference" and a reference accessed via the internet. Primary literature that is accessed via the internet should NOT be cited as an internet source. If journal articles, books, and similar documents, are accessed online through the databases, they are references like their corresponding print forms.

In addition, a common misconception regarding the use of material on the internet is that it is by its nature "free." Despite "open access" to the internet, someone owns a copyright for information on a webpage and thus permission must be granted from the copyright holder for reproduction (including all pictures, diagrams, photographs, etc.). It is standard practice to reference these sources. Failure to do so is plagiarism.

Also, remember that sites such as Wikipedia, About.com, and even search results from Google can be scientifically unreliable due to a lack of oversight. These are not peer-reviewed sources of information and are not necessarily written by experts. While certain facts may be correct (molecular weights, densities, etc.), it is best to check the primary literature for confirmation (often these sites have references at the bottom of the page, which you can follow and read for yourself). Any interpretations or conclusions regarding data should not be referenced.

Finally, work that is published online by another student may not be used under any circumstance, nor may it be referenced.

4.1.5 Using the search tools to find references

At this point, you may be asking yourself "How do I find the references I need?" Fortunately, there are several tools readily available that will help you search the literature. While each of them is designed slightly differently, the same general themes apply no matter which one you are using.

CRC Handbook of Chemistry and Physics

The CRC Handbook of Chemistry and Physics (often referred to only as the "CRC Handbook") is a comprehensive reference work that comprises literally hundreds of tables of scientific data. Included in these tables are physical constants, chemical properties, mathematical data and functions, and laboratory safety information. This is a really good place to start when you are searching for values, constants, and properties that you have reason to believe are well known.

Most libraries will have a physical copy of the book, but the online version allows users to search by chemical structure (written or drawn), which makes it even more powerful and easy to use. Most research universities have site license access to the CRC Handbook, which can be accessed conveniently online on their website at `http://hbcponline.com/`.

Note: although this a website, it is a web representation of a physical book (like most online references and journals). The 2017 CRC Handbook is cited as: "*CRC Handbook of Chemistry and Physics*, 98th ed; Rumble, J. R., Ed.; CRC Press: Boca Raton, FL, 2017."

SciFinder Scholar

SciFinder Scholar is the most widely used scholarly database in chemistry. It contains entries from two major indices: Chemical Abstracts and MEDLINE. Chemical Abstracts indexes new compounds and articles that appear in nearly every type of print media (book, journal, thesis, technical report, etc.). MEDLINE is a database of published papers related to medicine and biology. Together, they cover most of what chemists need. Note: you may need to be connected your school's network, or have access to a VPN, in order to register for SciFinder.

Some useful features of SciFinder Scholar include:

- The “Tools” menu allows you to further refine your answer set. You may remove duplicates, combine answer sets, etc.
- The “Get Related” menu allows you to view all of the references that are cited in an article, as well as all of reference that have cited that paper since.
- The “Analysis” and “Refine” options also allow you to categorize your results based on criteria you choose.
- Finally, you may save your search results for the next time you login.

Web of Knowledge

Web of Knowledge is an interface that allows simultaneous searches of several databases: Web of Science, Biological Abstracts, MEDLINE, and Journal Citation Reports. Web of Knowledge often contains information that is unavailable in SciFinder and the search engine works similarly to SciFinder, so it is another reliable resource for finding appropriate references. To access Web of Knowledge, follow these steps:

1. Login to Web of Knowledge through your school’s library site.
2. You may begin to search the database by topic, title, author name, etc. You may also search these criteria simultaneously by adding another field.
3. Refining your answer set is made possible by choosing from one of the tabs on the left hand side. You may also find the cited and citing references.

Google Scholar

The most popular search engine is Google. Unfortunately, searching for scientific information on Google almost always directs you to information that does not meet the peer-review standards of the scientific community. For example, a Google search for *electrochemistry of batteries* will direct you to a Wikipedia page on the electrochemical cell – hardly the kind of literature you need for scientific writing. Luckily, Google Scholar is a search engine that is designed for the academic world. It works just like any regular open-access search engine except that is searches the primary literature for your topic of interest. To access Google Scholar, follow these easy steps:

1. Go to the following URL: `http://scholar.google.com`. Note, this can also be accessed via the main Google homepage. It is recommended that you bookmark this site.
2. Search for a topic of interest directly or click on “Advanced Scholar Search” to provide more details.
3. Within “Advanced Scholar Search,” you have the option of searching by topic, author, publication name, etc.
4. You may include/exclude patent literature and limit your search to a particular subject.

4.2 Annotated Bibliographies

An annotated bibliography is a commented list of sources on a specific topic. It starts with a short abstract that summarizes the major takeaway points and is followed by the annotated references. Each reference entry is formatted according to standard reference formatting and is accompanied by a critical annotation.

As you become more knowledgeable and expert in the sciences, the volume of your scientific library will grow. While the list of papers that you’ve read will start off quite manageable, it will quickly become crucial that you find an organizational system that will allow you to classify and comment on each paper.

Otherwise, you will find yourself asking the question "now where did I read that?" – not a fun place to be when you go to write a paper.

The idea behind an annotated bibliography is that they become a good way to manage the references that you've read and value. Whether you are citing them in a paper that you are writing now, or you think that they might be interesting papers to re-read in the future when you are working on a new project, annotated bibliographies allow you to organize, summarize, and share the valuable reading that you've done.

4.2.1 Content

People who read annotated bibliographies want to gain from the experience of the person who has read and used the sources. They need a summary of the contents, and they also want a critical evaluation of the source.

They want to know: the major takeaway point(s) of each source, the source's intended audience, its relationship to the wider field of research, strengths and weaknesses of the argument, and whether it is detailed or broad. In short, the reader of an annotated bibliography wants a quick and effective insight into some of the sources you have used; either they want to recall the reason that they found the sources to be useful or they want to get an idea of whether (or how) they would be useful for their own work. They are, in effect, an executive summary of the sources.

4.2.2 Language and focus

The language of an annotated bibliography should be formal and objective, following the style of scientific writing. They are normally written in full sentences, but some use brief and incomplete sentences when space and brevity are particularly crucial. The focus is on the source ('the article presents', 'the author concludes ...'), and it is generally written in the present tense.

In an annotated bibliography you are required to outline the type, level, and quality of the information. Additionally, include the reason for which you find the source to be useful. Think of yourself as a reviewer of the material. Tell the reader about the text, what it covers, and in what way. Don't descend far into the specific details of the work. A sample annotated bibliography can be found at the end of this chapter.

4.2.3 Keywords

Adding keywords to your reference manager entries is the easiest way to help keep track of your work and make things easier to find in the future. You can add many keywords to each entry, and that will help you to sort things by topic, course, project, and idea.

Ideas for annotated bibliographies

Here is a general guide to writing an annotated bibliography:

Write your citations in the proper format (see previous chapter for more information), and follow with a descriptive and evaluative paragraph for each; make sure to include how it relates to your study. The following format may help (although you have free license to structure this how you like):

The authors studied _________________. Their hypothesis was _________________. They tested this hypothesis by _________________. They found _________________ which supports/does not support their hypothesis. This paper is important to my analysis of _________________ because _________________.

A thorough understanding of the scientific literature takes practice and finding quality references that reflect the state-of-the-art in the field can be time-consuming. Having worked through this chapter, however, you should now be well-equipped to search the chemical literature with ease, be able to distinguish and evaluate primary references, and properly format a list of citations – skills you will use throughout your scientific careers.

4.3 End-of-chapter Assignment

1. Consider the sample annotated bibliography on the next page.
   (a) Based on the theme of the annotated bibliography, use the research tools outlined in this chapter to find two more articles that would be appropriate to include in this annotated bibliography. Explain (briefly) how you found the source – what tool, what search parameters, how you refined your search, etc.
   (b) For each article you selected in (a), prepare an entry for the annotated bibliography. Don't forget to use proper formatting for the references.
   (c) Download the full paper for the Grushow entry. Do you agree with the annotated bibliography entry for this paper? Explain briefly. Add keywords to this article that you might use to categorize the paper. (You are welcome, and encouraged, to read all of the papers – they are really interesting.)
2. Use the research approaches outlined in this chapter, and the search tools that you've learned, to find (**at least**) four papers relevant to your most recent lab.
   (a) Briefly describe the approach that you used to find the sources
   (b) Briefly (no more than two sentences) explain why you picked these specific sources.
   (c) Prepare an annotated bibliography of these sources. Make sure to include an appropriate title and abstract.

4.4 Sample Annotated Bibliography

Below is an annotated bibliography from my files. It contains some of the more pertinent and interesting papers that I've read on the topic of misconceptions that first-year students have about how chemical bonds form. Hopefully it will give you some ideas about how annotated bibliographies can be used effectively to organize your work.

Common misconceptions of first-year students about chemical bonding (2013)
Prepared by B. Abrams, Department of Chemistry, Boston University, Boston MA 02215

For many students, learning chemistry – the study of a microscopic world that is beyond their tangible view – proves very difficult. Despite well-meaning intervention from instructors, new approaches, and updated texts, students leave high school and college chemistry courses with poor conceptions of chemical phenomena. Chemical bonding is among the most difficult concepts for students to learn properly, without forming strongly routed misconceptions.

In the past, many studies have focused on general misconceptions held by incoming students in chemistry and the persistence of those misconceptions. Recently, articles and studies have begun to focus on the misconceptions relating to atomic theory and bonding – arguably two of the more difficult areas for students. A common refrain in these articles is the need for instruction to be chemically-accurate, and for instructors to be precise and patient in their instruction.

Peterson, R.F.; Treagust, D. "Grade-12 students' misconceptions of covalent bonding and structure" *J. Chem. Educ.* **1989**, *66* (6) 459-460

> This article presents a diagnostic instrument to assess students' understanding of covalent bonding using a two-tier multiple-choice test. The survey of high school indicates that between 20% and 34% of students demonstrate weakness in topics related to classical bonding concepts (bond polarity, valence shell, ...). The study concludes that these results are consistent with the notion that high school teachers may show more concern with completing topics than helping students to develop authentic comprehension. Overall, this source is not particularly useful for a discussion of learning of modern bonding concepts, and is pitched towards a high school or low-level education audience.

Nakhleh, M. "Why some students don't learn chemistry" *J. Chem. Educ.* **1992**, *69* (3), 191-196

> The author argues that many of the problems that students face later in chemistry instruction is due to poorly-constructed models that they build early on during instruction. While this source does not directly discuss bonding, it provides insight into the process by which the misconceptions about chemistry arise: slowly, over time, and cumulatively. Two major points made in this paper are (a) about the way students visualize chemical systems and (b) the need to be precise in definitions so as not to confuse students. While this paper is not useful for a specific discussion of teaching bonding, it explains a lot about how incoming students think about chemistry, which is useful for planning how to teach them.

Grushow, A. "Is it time to retire the Hybrid Atomic Orbital?" *J. Chem. Educ.* **2011**, *88* (7), 860-862

This editorial letter presents a strong argument for eliminating hybrid atomic orbitals (HAO) from the curriculum. The author suggests two reasons for the persistence of HAO theory: they help to explain three-dimensional shapes of molecules and predict the orientations of atoms around central atoms. The author suggests that VSEPR alone is sufficient to accomplish these goals from a phenomenological point of view, without introducing fallacies about localized bonding orbitals or degenerate bonds in methane. The major argument of the paper is that it would be better to relegate discussion of bonding to MO theory alone, in a course that is appropriate, and not confuse students with a model gives results contrary to experiment (especially when structure can be reasoned from VSEPR alone). The paper is well-reasoned and convincing, and is a good reference for support of major curriculum reform in general chemistry.

Ball, P. "Beyond the bond" *Nature* **2011**, *469* (7328), 26-28

Pitched towards a general scientific audience, this opinion article presents a thorough discussion of the difficulties associated with the concept of a 'chemical bond.' The author gives a brief historical review of the concept of bonding, including recent complications introduced by our ability to use ultrashort pulsed lasers to probe chemical motion. The major focus of this article is to highlight the difficulty (impossibility) of properly defining a "bond" as a static thing, and that a new notion is needed to replace the long-outdated view that is commonly held. While the article is informative and authoritative, there is relatively little substantive discussion of future directions or outlooks in this area other than to abandon the traditional picture of a covalent bond.

CHAPTER 5

MAKING CLAIMS AND BUILDING AN ARGUMENT

5.1 Starting to think about argument

All writing is about making an argument. Each field has its conventions regarding the structural and organizational details of research papers – even sub-disciplines may utilize different conventions. 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.

Irrespective of the type of argument that you are going to make, you will make a strong claim that is based on grounds (evidence, data). The two most common types of grounds that we will rely on are: the *exhibits* that you prepare (based on your experiments) and the *research* that you do (in journals and books). As a result, 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, (b) prepare *effective and convincing exhibits*, and (c) research in the literature to learn more about the topic of your study and find information relevant to your experiment. 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.

5.2 Planning your paper's argument

As we've already said, all writing is about making an argument. In this context, "argument" can be used interchangeably with the paper author's "interpretation" of the results to an audience. These claims are made based on the exhibits that we prepare, the results of the experiment, and a thorough understanding of the background material (research in the literature).

An argument is made up of at least three key components: a claim, grounds, and warrants with thorough backing – these three components make up the minimum logical argument that can be made. In addition, many arguments also contain additional, but not always necessary, components: backing (for warrants), qualifiers, secondary claims, and counter-claims with rebuttals. For now, we will focus on the first three components.

5.2.1 Integral components of a logical argument

A **claim** is an assertion that you are making about the nature of the world and is the cornerstone of the argument. The entire purpose of writing your paper, and making your argument, is that the reader will agree with your claims. The claim is a conclusion, a statement of reasoned fact, that is the focus of the paper. Your claim should answer a question such as "*what do I believe based on my work and want others to believe as well?*" or "*what position do I want my audience to take?*" A claim is not the same thing as 'what value did you get?' Rather, you should think more globally about what your results mean and what conclusions you can make based on them. Consider the following:

- Think about what point(s) you want to make, not what paragraphs you want to write. What is the one idea that you want a reader to walk away from your paper with?
- Make sure that you've clarified *exactly* what you want to say. Don't be wishy-washy and make points that weaken others, that contradict other ideas that you've brought, or that are not effective.
- Avoid negative proofs: 'A is bad, so B is better' is not a strong claim.

Grounds (or data or evidence) are the foundation of the argument; these are the facts and evidence that are brought to support the claim that is being made. In scientific inquiries, these grounds can be from experimental data, conclusions made from an experiment, or cited research in the literature. Your grounds are the answer to a question like "*what do I have to go on?*", "*what data do I have to support my conclusions?*", or "*where must the audience start in order to eventually agree with my claim?*" Think about the exhibits that you intend to display to the reader:

- How do you intend to present the data: in paragraph only, with the help of a table or figure?
- Exhibits (data, figures, and tables) are there for you to support your argument. Never present extra data without a good reason. Ask yourself: which data need to be presented at all, what belongs in the Supporting Information, or what need not be included at all?

There is usually a large disconnect between the claim that you intend to make and the data/grounds that you bring to support it. **Warrants**, or warrant statements, are the links that are used to make the connection between the claim and the data. Warrants are statements that are brought to give support to the data and show how they support the claim.

- Warrants answer the question "*how do I get from evidence to claim?*" or "*what are the trails of thought that get us to the conclusions that we've drawn?*"
- We never assume that the reader will immediately jump to the same conclusions that we do. For example, consider the claim that "candy X is bad for you" (claim) based on the fact that it contains "20 g of sugar" (data). While this may seem like common sense (it is), in the sciences it is important to bring warrants to bridge this gap.
- More details about the types of warrants that are commonly used in writing can be found later in this chapter (section 5.4).

Typically, warrants require **backing** to substantiate them. Backing refers to information from prior studies (with appropriate citations), or scientific principles, that are brought to support the statements being made. Sometimes the backing will be discussed at length in the prose, and other times it will only be cited. The depth to which backing is discussed depends on the audience to which you are writing.

5.2.2 Putting these components together in a simple example

Together, a claim, data, and warrant comprise the smallest unit of an argument. Let's consider the following short argument that uses only these three elements.

Let's say that we intend to argue that a building on campus – the Metcalf science center (SCI) – is on fire (claim). We will need evidence to support that belief. It is the thick, black smoke emanating from the 4th floor of the building (data, grounds) that motivates this claim. Since smoke of this color and density is one of the most ubiquitous signs of fire[1] (backing; the superscript "1" implies that we would have a source that would support this assertion), so we conclude that there is a fire in Metcalf (warrant statement).

Graphically, the argument in the above example can be effectively represented by the Graphical Representation of Argument (GRA) diagram depicted in Figure 5.1. These diagrams are an easy way to conceive, plan, and organize your argument before you start to write. By preparing a GRA before

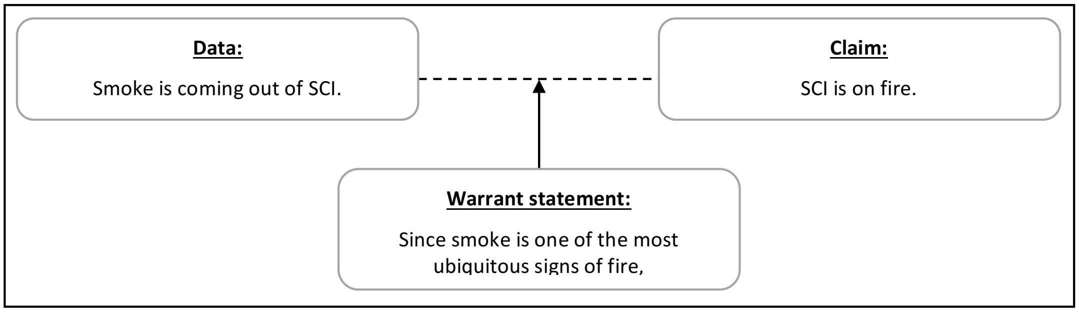


Figure 5.1: Graphical Representation of Argument (GRA) diagram for the example argument outlined about a fire in Metcalf.

you start to write, you can make sure that all of the important components are present and that your argument is cogent. Then, once you've decided that your argument is sound, you can write your paper with confidence. This process will save you a substantial amount of time in revisions and rewriting.

It is important to note that this is a very simplistic example with limited data and warrants. Since this is a minimalist argument, we expect that it might not be very persuasive. Adding more warrants, with relevant backing, will make the argument much stronger.

Your GRAs will look very different. For the types of arguments that you will make it is all but guaranteed that you will need substantially more evidence (grounds) and warrants to substantiate your claims. Hence, please do not think that this shape of GRA – with only one piece of data and one warrant – is universal.

5.2.3 Assembling graphical representations of arguments (GRAs)

Your graphical representation of argument doesn't need to look polished or fancy. The most crucial thing is that your GRA contain the *very specific* and detailed components that you will plan to use in your argument. Start by jotting down all of the grounds (data, figures, tables) you might think about including in your paper. Consider using a whiteboard or PostIt notes to make things easy to rearrange as you work – you won't get it right on the first try.

Once you've surveyed all of your data, and have finished your research, decide on the claim(s) that you intend to make. Jot these down as well and add them to the board. Connect each claim that you want to make to the data that is the foundation of that claim. It is conceivable that a single piece of data could support multiple claims.

Next, you will need to prepare warrants to walk your audience from your grounds to your claim. There is no set number of warrants that are necessary for a given claim. Some claims are easy to make and will require few warrant statements, while others may require many warrants. The number is not important; rather, focus on making a strong argument that is convincing.

Finally, do not worry about the order of the items when you are constructing a GRA. Rather, the GRA is a brainstorming tool to allow you to assemble all of the components that you find necessary. Once you have all of it in front of you, then you can start to think about the best order to present your argument. Arranging these components into a scientific paper is discussed in chapter 6.

5.2.4 Sources necessary for arriving at a strong argument

One of the biggest mistakes 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 scientific literature — these students will oftentimes write their entire paper before ever engaging outside sources (if ever). Those papers will rarely, if ever, by very good.

A common question that instructors 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 instructor deems the minimum acceptable number for the paper. 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 cite all of the sources that you *actually consulted* when preparing your argument, and no more. The most important thing to remember is that sources cannot be relegated to an afterthought. These sources are the core of your understanding and the backbone of your argument. They are the heart and soul of the claim that you want to make.

5.3 Additional components of strong arguments

Up to this point we've focused on the core components of logical arguments: claim, grounds, and warrants. There are three additional components that can be used to strengthen an argument: qualifiers, backing, and counter-arguments and rebuttals.

When a warrant statement is completely obvious, then **backing** is not completely necessary. This is rare in the sciences. In scientific writing, it is crucial that we provide backing for warrants to establish the reliability and relevance of the warrant statement, or as a secondary source for the warrant. Use of backing is especially important when the leap from data to claim is not small and would require several "steps." In these cases, use backing to establish a step-by-step chain that allows your audience to follow your argument without developing questions about your logic.

- To decide if your warrant needs backing, ask yourself the question "*is the move from grounds to claim safe right now?*" or "*would everyone make the leap from evidence to claim that I just made?*" If you answered either of these questions in the negative, provide backing for your warrant by citing other research papers, common knowledge, or further experimental evidence.
- Results from other studies, fundamental concepts from the field of science, and methodologies are conceivable sources of backing.
- The amount of backing necessary scales directly with the complexity of the topic and warrant statement. It is feasible that a single warrant might require multiple sources and types of backing in order to be secure.
- Sometimes it is sufficient to just cite the backing. This is the case when the details are not necessary to your argument, but you are directing the interested reader to the source(s). In many cases, however, you will need to include a discussion of the principle from that source in your prose. In either case, properly cited references to the sources of your backing are a must.

Qualifiers are used in the wording of the claim in order to modify and limit the scope of the claim. Words such as 'usually', 'often', and 'under these circumstances' can be used to limit the claim. While this may seem to weaken the strength of the argument, it accomplishes the opposite. By appropriately qualifying a claim, the author effectively identifies and states the limits of their claim; this allows the reader to be confident about the reaches and limits of the claim being made. If your claim is universal, and has no appreciable limitations, then it does not need to be qualified. In most cases, however, a qualifier is necessary to acknowledge the limits of the claim.

- You should ask yourself "*what limitations do you see to the conclusion(s) that you are trying to make?*" Remember: limitations are not bad, they are just the limits of the claims.
- Does your claim apply to all situations and samples? If not, how could you make this clear in the most simple way. Phrases like "*of the ones we sampled*" or "*of this type*" can qualify a claim.

Finally, a move containing a **counter-claim** with subsequent **rebuttal** is an effective way to explore, and then explain, the limits to the claim. A counter-claim is a possible objection to your claim that someone reading your paper may have, and a rebuttal is your response to that counter-claim. Used properly, counter-claims and their rebuttals are a way of acknowledging the types of objections that someone reading the paper might bring up and then dismissing them. These are especially useful for acknowledging exceptions that might otherwise invalidate the claim or when you are contradicting previously published works in your paper.

In a conference presentation the attendees would have the opportunity to raise these concerns with you extemporaneously. In a paper, however, you should attempt to anticipate any meaningful objections and dispel them convincingly. As these counter-claim and rebuttal moves are not the cornerstone of your argument, they would typically be included last in your discussion.

- Ask yourself "*What objection might the reader have to my claims?*", "*what possibilities might interfere with my argument?*", or "*are there exceptions that would invalidate my claim?*"
- Structure and back-up rebuttals to these possible counter claims as a way to reduce the reader's uncertainty in your claim.
- You will likely need support (warrants, backing) to support any rebuttals.

Proper use of rebuttals will strengthen your claim as they provide a way of dispelling possible detractors and acknowledging fundamental limitations. Often, delving into a rebuttal will lead to another claim that will be argued and discussed using these same components (data, warrants, etc.).

5.3.1 Revisiting the simple example about a fire in the building

Let's revisit the earlier, somewhat cheesy, example argument about a fire in Metcalf, and add qualifiers, backing, and rebuttals.

"From the substantial amount of black smoke coming out of the 4th floor of SCI (data), we conclude that it is likely (qualifier) that the Metcalf Science Center is on fire (claim). Smoke of this color is one of the most ubiquitous signs of fire[1] (warrant), which generally produces the smoke as fuel is consumed[1,2] (backing). This implies that it is very likely (qualifier) that there is a fire in Metcalf (restated claim), unless the smoke is being generated by a reaction in a research lab (counter-claim). Given, however, that the building is currently empty for intersession (backing to rebuttal), it is unlikely that the source of the fire is from a research group (rebuttal)."

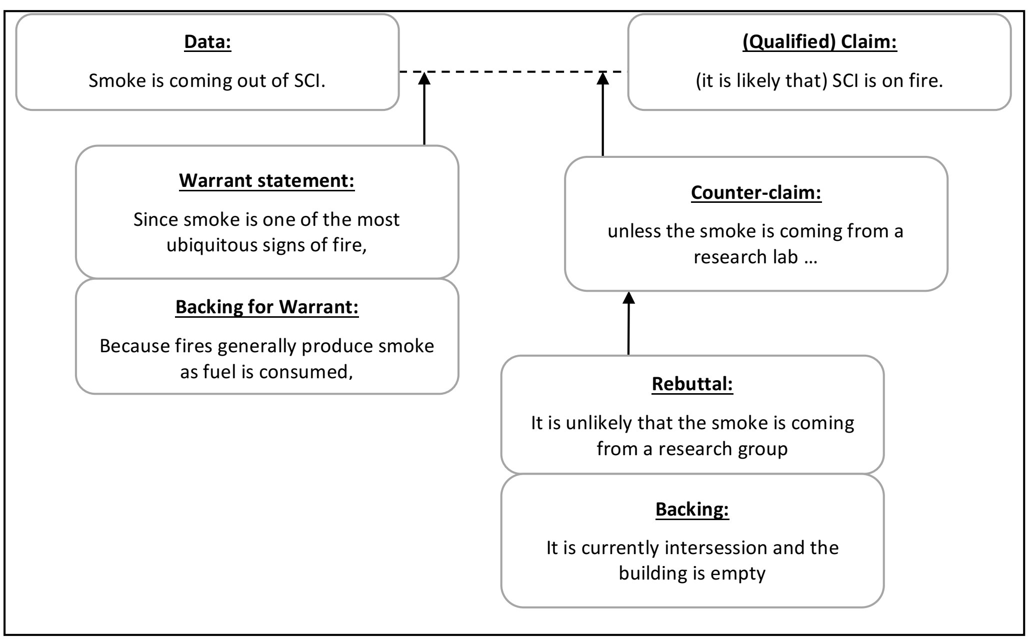


Figure 5.2: GRA for the extended example argument about a fire in Metcalf that contains all six elements of logical argument. **Remember:** this shape of GRA is not universal – yours will likely look very different.

5.4 Common warrants used in scholarly papers

Warrants can take many forms and depend on the type of argument that you are trying to make. In each case, these warrants must be based in sound reason and be thoroughly researched. The following is a list of some of the different types of warrants that you might consider using. While this list is far from exhaustive, it is a good start for identifying the types of arguments that you can make.

- **Argument based on generalization:** this common form of reasoning involves making the assumption that what is true for a well-chosen sample is likely to hold true for the larger population or group. Alternately, this argument is that *some things* consistent with the sample can be assumed about the larger group.

  Backing for these types of warrants are discussions of things like the nature of the sampling method used and why it is ok to generalize from the sample used to the larger group.

- **Argument based on sign or clue:** this type of argument uses the notion that certain types of evidence or trends ("clues") are symptomatic of some bigger principle or situation. Based on these well-established clues we can argue for some underlying cause or situation that is not directly observed.

  In making this type of argument it is necessary to include support (backing) for how the clue is indicative of the underlying situation that you are implying is present.

- **Causal argument:** in a causal argument the author argues that the results observed are the result of, or affected by, a specific factor. While these arguments tend to be very common in scientific studies, they also tend to be among the most complex. There are two main dangers when using a causal argument: (1) conflating correlation with causation and (2) mistakenly basing the argument in *post hoc, ergo propter hoc* (since it was this way after the fact, it must be as a result of the fact). Also, a warrant implying causation will require substantial backing to establish the underlying principles.

- **Argument from authority:** involves stating facts that are agreed upon by authoritative sources and people. Relying on state-of-the-art methods, instrumentation, and frameworks constitute argumentation from authority. In these cases, make sure to cite the seminal works in the field – there are almost always more than one source that falls into this category – as backing for your warrant statements.

- **Argument from principle:** similar to arguments from authority, these arguments are based in the principles underlying the field of study and build upon prior work in the field, even if there might not be complete agreement in the area. Citing the studies that establish, or even perhaps refute, these principles is absolutely necessary.

Most successful papers will involve multiple well-backed warrants. Determining the warrants that you will use, and sufficiently backing up these warrants, will likely require you to do research to locate, read, and digest papers and books in the field of study. Citing papers, books, and review articles that you've used in cementing your argument is a cornerstone of the scientific process.

5.4.1 Avoiding logical fallacies in your writing

We know what we believe and why we believe it, and so it can sometimes be difficult to understand why someone might object to our arguments. Novice scientific writers have a tendency to stumble by basing their argument off of a logical fallacy. The two most common of these fallacies are: (1) arguing that the value of something is established by the lack of value in something else, and (2) because the results are what they are, it must be the case that the result must have always been that way.

The first of our logical fallacies is quite normal in our day-to-day lives. We often exhibit preference for something because it is not as bad as the alternatives. While that might be true, being less bad then something does not make that thing good. An argument about the value of something must be primarily based on its positive attributes and not on the negative attributes of other things. For instance, if you intend to argue that we should eat sushi for dinner tonight, the argument ought to be based on the good reasons to eat sushi and not the reasons why you don't want to eat other foods, like pizza. Arguing that pizza is a bad choice for dinner will not necessarily convince someone that they should have sushi instead; rather, it will convince them not to eat pizza. (For the record, either pizza or sushi would be a welcomed dinner.)

The second common logical fallacy is properly termed *post hoc ergo propter hoc* – since outcome Y happened after we did X, so outcome Y must be caused by X. A common example of this mistake is a common belief held by anti-vaccine advocates: they see that some people become diagnosed with illness shortly after being administered a vaccine, and they erroneously infer that the vaccine must have caused the illness. Said otherwise: proximity and sequence does not establish causation.

Affirming the consequent is another such fallacy. In science we build experiments to disprove hypotheses, not confirm them. Here, a scientist might seek evidence to confirm their hypothesis, which can be problematic. It is very possible that the design of the experiment, and some other variable, is responsible for the outcomes, and not the variable being manipulated.

Finally, false analogies can be very problematic in the sciences. Much of the molecular and biological worlds are, for the most part, unseen. As a result, we rely heavily on analogies to help us model the systems we study. Be careful about applying inappropriate analogies, and their underlying principles, in forming your arguments.

5.5 Grounds – choosing relevant data to include

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. Primary data are never presented in the body of a scholarly paper.

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 (as *grounds* or *backing*), and those which are not necessary. Extensive, but relevant, data should be included in the *Supporting Information*.

Example 5.1: Choosing relevant data

To illustrate, consider the product of a synthesis: the only piece of data that will likely be included in the argument is the percent yield. The raw masses are not relevant and should not be given. Additionally, if you performed ten replicate syntheses, then only the average and confidence interval of the percent yield is relevant. If would be grossly inappropriate to report all ten measurements, the standard deviation, and the rest of the raw data in your paper. That said, if there were outlying attempts with very low or high yields, these might be discussed separately in the paper.

5.6 Helpful Tips

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 details and components. Other common mistakes include:

- Using data or statistics as warrant statements – they definitely do not speak for themselves. Focus on the science and concepts as warrants and backing (not statistics or values). That said, under the right circumstances, data can be used as backing to warrants.

- Making a vague GRA. GRAs should be dense with specific information, statements, and backing: terse in verbiage, rich in content. The goal will be to take the GRA and expand directly into a paper without much additional research.
- Always include references in your GRA. Keep the sources that you use organized and connected with the points that you are making. This will make your paper-writing much easier. In general, all backing that you did not generate in your experiment and all concepts that are not common knowledge will need a source.
- Don't start working on a GRA as if it will be your final product. It is best to allow for flexibility in your workflow. Consider working with Post-it notes or on a whiteboard. Once you're happy with your GRA's structure, prepare a final version. Microsoft Word, or websites like Lucidchart (`Lucidchart.com`), can be used to make a polished final product.

5.7 End-of-chapter assignment

1. You intend to make a presentation to a group of restaurateurs to persuade them to change their service/wait-staff policies to eliminate tipping and move to a fixed service charge. Work in small groups (2-4 students) to answer the following questions.
   (a) Classify each of the following statements as claims (C), data (D), warrant (W), backing (B), counter-claim (CC), or rebuttal (R).
   - "Servers may have an adverse reaction to the new policy."
   - "Hiring new servers requires a large investment of time and money in things like paperwork, training, and searching."
   - "An 18% service charge should be added to patrons' checks in lieu of tipping"
   - "High turnover of wait-staff is very costly."
   - "Servers making a dependable wage are less likely to seek other employ."
   - "Adding a service charge will result in a more-steady income."
   - "Service charges eliminate patrons wondering how much to tip, and leads to more equity in service compensation."
   - "Service may suffer as a result."

   (b) Draw a GRA for this argument.
2. Let's discuss a possible claim for a paper about a candy that we've studied.
   (a) Consider the following possible claims for an argument about why a certain candy is bad for you:
   - "Candy X is bad, because candy Y is better" (really bad claim)
   - "Candy X is the worst candy in the world ..." (better, but not great)
   - "Of the candies studied, candy X was found to be the most deleterious for hypoglycemic patients" (good)

   What makes the first two examples poor claims? What makes one claim better than the others?

   (b) What types of warrants and backing might you need in order to substantiate the better claim?
3. Consider a recent lab that was performed and go through the steps that you would take in preparing a strong argument:
   (a) Complete your data analysis. Tabulate the data and indicate where in the paper (or Supporting Information) these would be included. Primary data should not be included. List any exhibits (figures or tables) that you prepared in your analysis. What exhibits, if any, would you use in the actual paper? Explain.

(b) What is the *objective* of the experiment? Suggest a possible *motivation*.

(c) Based on your work in lab, and the research you've done, suggest a strong claim that will be the basis of your argument. What makes this claim strong? Explain. Note: strong claims are not necessarily grandiose or Earth-shattering; rather, a strong claim is usually the broadest claim that is supported by the data and your research – something meaningful.

(d) After completing your data analysis and preparing your exhibits, prepare a Graphical Representation of Argument (GRA) for your paper using the questions from earlier in this chapter to help your work. It is likely that you will need to do some research in order to form your argument.

(e) What types of warrants or arguments did you employ? Explain.

Part II

Journal Articles – The primary vehicle of scientific communication

CHAPTER 6

STRUCTURE OF ABRIDGED SCHOLARLY PAPERS

6.1 Structuring an argument into an abridged scholarly paper

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. In this book we focus on the two most ubiquitous 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 write peer-reviewed papers in a voice that gives the illusion that the scientist does not affect the results, and they refrain for the most part from using the tenses that imply subjectivity. 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.

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

Variability in Journal Article Structure

In this writing guide we provide a general framework for writing a journal article. As you read more scientific journals and articles, you will see that structure is not always consistent. In other words, not all articles will follow the framework discussed in this guide.

While there is variability between disciplines, *as well as within disciplines*, the principles of scientific writing are identical in all cases. Section headings may vary, but regardless, the same content is always there, it may just be parsed differently. Always follow the guidelines specific to your intended journal or course.

6.1.1 Framework of the typical journal article argument

The main sections of a journal article (Introduction, Methods, Results and Discussion/Conclusion) are not disjointed pieces, though they are written in such a way that they *can* be read standalone. 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:

- *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 chapter 1; (b) identifying the gap: what exactly did you study? Why? This is the *Objective* of the experiment; and (c) summary of the literature/background pertinent to the study.
- *Methods:* what you did in explicit detail – enough that an expert reading the paper should be able to reproduce the work, but without being overly verbose or including unnecessary details. Demonstrating the validity and rigor of the methodology is a necessary prerequisite to convincing the reader that the results have meaning. It is important to note that the intended audience will play a large role in determining the amount and types of details that are necessary for this section.
- *Results and Discussion:* the argument – the beliefs that you now hold as a result of your study and what you now want others to also believe. 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 components of the GRA that you outlined: claim, grounds, warrants, etc.

Results... then Discussion

In many journals, **Results** and **Discussion** are two separate sections. In this case, the results section simply reports your results without explanation or editorial. Present your exhibits in a clear and organized manner, including descriptive text. You are not analyzing the meaning of your data here, you are just stating the facts of what you saw in your experiment.

In the separate discussion section, you now analyze how your work relates to other sources and why you saw these particular results. This is where you tie your paper together, analyzing how your claims fit into the larger picture of your topic. Bring in arguments from other sources (cited properly, of course) and state how they support (or do not support) your work. Often, the last paragraph of the Discussion section is analogous to the *Conclusion* mentioned below.

- *Conclusion:* This section includes an extremely concise summary of what was accomplished in the study (usually only one sentence), in the context of the objectives. This is not a restatement of the claim. Additionally, the author makes claims about the relative successes of the work, suggests possible future work, and – most importantly – explains the broader impacts that the results will have on the field and society.

Not all papers have conclusion sections

Some papers are written without a formal "conclusion" section. Again, make sure you are following any journal-specific guidelines. The same information can be presented in the last paragraph of the Discussion.

The remainder of this chapter will focus on the components of what we will term *Abridged Scholarly Papers*, which will not include Introductions or Methods sections. Abridged papers will present the argument in its entirety, without the need to write the laborious sections that give the context and background.

6.2 Results and Discussion Section

The Results and Discussion section is the cornerstone of the scholarly paper – this is where you present your argument and claims, based on the results of your study and in the context of the greater scientific objective. The Results section starts with restating the objective of the study, and then data and exhibits are presented (the proper formatting of exhibits was discussed in chapter 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 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. Use GRAs and checklists (discussed later in this chapter) to organize your argument before beginning to write your Results and Discussion.

6.2.1 Content and Organization

Use checklists and GRAs to organize your thoughts, and your points, before you start writing your Results and Discussion. A detailed checklist, with the actual points that you intend to make, will help you to quickly and effectively write your paper. The beginning of the Results and Discussion section, or each subsection in the Results and Discussion, is a concise restatement of the objective of the study (in no more than one or two sentences). The specific, take-away results of the experiment and their context are then presented (claims).

To present your results you will need to be bring *select* exhibits (grounds; see previous chapters for how to determine if data is relevant to be included and the best methods for displaying it) and explain to the reader what they should learn and infer from them. Captions of figures are tremendously important for getting points across, but the prose in which exhibits are discussed is paramount.

The most important part of the Discussion is to make a clear argument about the meaning and scope of your Results (warrants). If the objectives of your study were partially met, or the hypothesis was supported with exceptions, this should also be explained clearly and reasoned well (including qualifiers, counter-claims, and rebuttals). Make sure that your explanations of the concepts are clear and are supported by references to scientific literature in order to shape a strong argument about your results. Remember, experiments are not about accuracy and precision of results – these are details. Make sure that your argument makes sense and that the points (warrants) you make are done in support of your argument.

Additionally, one thing to keep in mind is that most of the experiments that you will perform in a four or eight hour lab session are of limited scope and length. Consequently, the types of claims and the amount of results that you have will tend to be minimal.

Finally, remember that the Results and Discussion is not the section for overarching generalizations about the overall success or failure of the experiment. Those types of statements and discussions are left for the Conclusion section. Always look for the specific instructions in each journal – sometimes there is no separate Conclusion section. Rather, this information is presented as the last paragraph in the Discussion section.

6.2.2 Format and Style

The Results and Discussion section will consist of multiple, topical paragraphs and relevant exhibits (tables, figures, and equations). A Results and Discussion section that consists uniquely of tables and figures is not appropriate.

While there is no page limit for this section, your goal is to keep the Results and Discussion as concise as possible. If your experiment contains multiple (more than two) central results, then you may find it useful to break your Results and Discussion into smaller subsections. Each subsection is about a specific claim, and should start with a heading (e.g., *Spectral Data* or *Plasmid Structure*). Do not use "Part ..." in your headings.

The Discussion consists almost entirely of prose. While the discussion should be persuasive, it must also be objective (i.e.,*anyone* would come to the same conclusions based on your data). Relevant chemical equations, tables, and figures are also referenced 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; it is rarely, if ever, appropriate for you to direct your reader to see the Supporting Information).

Discussion section

In some journals, the Discussion section is separate from the Results section. It is appropriate for the Discussion section to follow the same order as the Results (and, when appropriate, Experimental). It is not necessary to separate the Discussion into subsections with headings, unless it significantly contributes to the readability of the section.

6.2.3 Proper use of Exhibits

All exhibits – tables, figures, and equations – must be referenced by number in the text of the paper. Do not use directional indicators, such as above or below, as the exact location of exhibits can often change before publication. Additionally, make sure that all exhibits are properly formatted, and that all figures have meaningful captions (see Chapter 2 for additional details).

6.2.4 Voice and Tenses

In many fields, such as chemistry, substantial portions of papers are 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 claims that are gleaned from the research are in the present tense ("the structure indicates that ...").

A movement towards the active voice

It is becoming more common to write papers in the active voice, even in chemistry. Two of the reasons cited for this change are (1) that papers written in the active voice are often more direct and concise, and (2) that many authors do not write well in the passive voice. Your mentors and instructors will be clear about their expectations regarding the voice in which you write your papers.

For more information about the debate over passive and active voice, see the presentation posted on the ACS website at: `https://bit.ly/2NAXd2S`

6.2.5 Sentences, paragraphs, and sections

Constructing an effective paper that flows can be a challenge in any field, not just in the sciences. Having thoroughly brainstormed and planned your paper, constructing the prose is the final challenge. It is best to keep the following in mind:

- A *sentence* should be one, complete thought. It is inappropriate to discuss multiple, unrelated ideas in a single sentence. Likewise, it is best to avoid small declarative sentences when a single sentence would do.
- Each warrant will be discussed and expounded upon in a single *paragraph*. All of the backing and explanation necessary to successfully make the warrant stand should be grouped together.
- Each *section* of the results and discussion should completely discuss a single claim or argument. If your study answers multiple questions, or presents several results, then the results and discussion should be broken up into meaningfully titled subsections.

More on how to construct an effective results and discussion section is presented in section 6.5.

6.2.6 Helpful Tips

- Always start your Results and Discussion with a restatement of the objective of the study. This is necessary because each section of a paper needs to stand alone.
- Make sure to be concise and avoid being overly verbose. While it is important that the Results and Discussion 'flow', it is also important to keep it relatively short and to the point. Start by making a GRA and expanding it into a checklist.
- Avoid erroneous coordinating conjunctions and avoid grouping unrelated ideas in a single paragraph (let alone in a single sentence). Unrelated ideas must be discussed separately and thoroughly.

Example 6.1: Hard to make and long-living mutants

It is very possible that the mutant you studied was both "hard to make **and** long-living" compared to the wild type. That said, these are completely unrelated ideas, and each of these should be a separate discussion in your paper.

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

Example 6.2: 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 ($N = 10$) 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 of your Experimental section you would report that all confidence intervals were computed at the 95% confidence limit.

- Do not summarize the experiment in the Results and Discussion. A summary of the relative success or failure, in brief, is made at the beginning of the Conclusion section. The discussion section should involve argumentation of your claims with relevant details. That said, it is important to make sure that you state whether or not your results support your original hypothesis.
- Avoid being vague – specific details are compelling. Also, remember to always cite your sources for backing.
- Make sure that your assertions are supported by properly-formatted references to the scientific literature. Also, be careful to make assertions that make sense! For example: losing product during filtration is not a good source of uncertainty when the experimental value is larger than expected. (Remember: instructors and lab partners are not sources of uncertainty/error; human error isn't a real thing in scientific writing.)
- **Never** reference your supporting information. If it is critical information, then it needs to be presented in your paper.

- Avoid using an informal tone in the Results and Discussion. In an effort to be persuasive you may be tempted to flirt with other moods – do not. It is more important that the Results and Discussion remains objective.

6.3 Conclusion Section

The conclusion ties together the entire paper. 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 claims/findings, and conclusions of the study, particularly the larger ramifications.

Some journals don't have separate Conclusion sections

Remember, some journals do not include a separate Conclusion section. Rather, this information may be presented as the last paragraph or two of the Discussion.

6.3.1 Content and Organization

There are three major components of the Conclusion section:

1. *Summary:* Briefly summarize the main conclusions of the study, including a brief restatement of the objective/goal of the study and claims. This is not a repetition of the first part of the Results and Discussion; rather, this is a summary of what was achieved and what the reader should take away. Were the study's objectives achieved? If so, to what degree? If not, how unsuccessful was the experiment? Note: there is no need to re-prove your claims; you did that in the Results and Discussion.

2. *Future Developments:* Suggest, and where appropriate explain, any future development or work that could be done as a result of this study. In other words, *"what comes next?"* These ideas and 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. 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?"* Note: what you learned does not refer to the *educational purpose* of the lab (titrations, UV/Vis, gel electrophoresis, etc.). This is referring to what was learned from the experiment (e.g., the best cereal to eat for iron is ...). How does this change the world? In general, considering that these are undergraduate labs, there is likely to not be any world-changing global ramifications. That is ok. Discuss the ramifications without resorting to hyperbole.

   It is very possible, especially if the experiment was not successful (or had limited success), that there are no global ramifications to the work. In this case, focus more on suggesting methods of improvement to experimental design, keeping in mind "human error" is not valid.

6.3.2 Format and Style

Voice and Tense

Unlike the Results and Discussion section that was written in the present tense (claims) and past tense and passive voice (results), the Conclusion discusses the present and the future. Keep the following in mind:

- *Summary:* The summary is about an experiment that was performed in the *past*. This component should be written in the past tense and passive voice.

- *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.* In either case, 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.

Passive voice in Chemistry

As discussed above, most of scholarly papers are written in the third person and passive voice in chemistry. 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. As a result, it is important to remember to avoid writing your conclusions in the first person (I or we).

Length and Depth

The Conclusion is the shortest part of the research paper, usually a paragraph or two that should generally not exceed half of a page. Conclusions will almost never present new exhibits.

6.3.3 Helpful Tips

- Avoid going overboard with the familiar and personal voice in the Conclusion; make sure that the Conclusion still reads like part of a scientific paper and not a personal notebook.

Example 6.3: Conclusion

Incorrect: "Completely abandoning the field and reinventing the wheel will lead to better precision."

Correct: "Ensuring location consistency in the collection at the Charles River would likely decrease variation introduced by sampling."

While the first statement may sometimes be true, it does not give any real constructive suggestion (your assertions and suggestions should be specific). Additionally, it is written in a manner that leads the reader to believe that the author will definitely implement their future development work.

- Suggestions for improvement and future work should be possible and reasonable. 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. Make sure to cite your sources.

- Don't restate your claims or re-argue your position – you did that in the Results and Discussion. The Conclusion is about summarizing the paper and looking to the future.

6.4 Putting together the complete, abridged paper

6.4.1 Each section stands alone

Keep in mind that scientists rarely read a paper from start to finish. Instead, we usually 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/Methods). 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, more accurately, a rephrasing of them) appear in the text as the exhibit is being discussed.

6.4.2 Appropriate format for research papers

Your papers will usually be comprised of two parts: the paper (including references) and supporting information. The paper will always start on a new page with an appropriate title, the name(s) of the author(s), and the affiliations of the authors. References do not start a new page, but follow immediately the conclusion of the paper.

Write your title and abstract last, once you've completely digested the message of your paper. The title must be specific and informative. The goal of a title is to inform the potential reader about the content of the paper and to entice them to read the paper. Your title should not be copied from a lab manual or be a throw-away. Additionally, your name, the name of your collaborators (i.e., lab partners), and the name and address of your institution are included. An asterisk (*) next your name denotes that you are the corresponding author. In some undergraduate courses you may be asked to include the name of your instructor and your course number (and section) with your title. This should follow the institution name.

The length of the title is often indicative of its quality. Titles that are too short (3-4 words) almost always lack specificity, while overly long titles (15 or more words) are equally inappropriate. Specificity is key in titles; make sure to use terms that are specific to your paper: the subject studied, approach used, and species names (if any). It is best to avoid using flowery terms and unnecessary filler words. Symbols and equations are almost never permitted in titles. Additionally, it is proper to omit small words (e.g., The, A, or An) at the beginning of a title.

Example 6.4: Sample Title

Incorrect: Acid-Base Titrations

Correct: **Determination of the pKa of Acetic Acid via Potentiometric Titration with Strong Acid**

Binyomin Abrams* and Sample Name
Department of Chemistry, Boston University, Boston MA
(Submitted to: BI 421, TF: name here)

In the case of the second title, it is much more clear *exactly* what experiment was performed and what the reader can expect to read. Notes: (1) the asterisk (*) is used to indicate the corresponding author; (2) the line beneath the address is because this is for a course, and so the name of the instructor and course number are included.

In journals, authors may use the *Supporting Information* (also referred to as the Supplemental Material) to include extra material that they feel that the reader might be interested in reading, but is tangential to the actual article. Typical items in the Supporting Information are (1) sample calculations (rarely found in journal articles, but you must always give one per calculation in your labs), (2) spectral data that is not a central result to the paper, (3) unpublished results that could shed light on your work, and (4) anything that you feel will clarify the reader's understanding of the work. Since all papers are posted online these days, Supporting Information sections have become more expansive and more utile.

6.4.3 Overall considerations for abridged papers

There is a lot to consider when approaching your abridged paper. Consider the following:

- Start with a good GRA (see chapter 5) for your paper. Use this GRA when planning your checklist (see section 6.5).
- A good checklist for your paper is necessary in order to produce a high quality paper. Make sure that your checklist is consistent with your GRA.
- Focus on developing a **concise** paper that has a good flow and a **strong argument**.
- Make sure to follow the guidelines about what to avoid in scientific writing (chapter 7).
- 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. Make sure that each section stands alone.
- Make sure that all exhibits are referred to by number in the text of the paper, and that they follow proper formatting (see chapter 2).
- Always remember to look over your work with a critical eye for the 'common mistakes.' They are so named because they are very common!

6.5 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 in an order that makes sense. Start with a GRA and expand it into a checklist.

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.

6.5.1 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 questions outlined in chapter 5 to guide your research and construct a GRA. Make sure to keep track of the sources that you used in your research. It is helpful to label the components based on their role (claim, grounds, etc.).

3. *Parse your GRA and prepare a checklist:* Expand your GRA into a checklist of items that you intend to include in your paper, in an order that makes sense. Put stronger and more compelling evidence first and less-important elements later.

4. *Checklists should be detailed and well-organized:* Each warrant should be a separate bullet point in your checklist, and each warrant should have multiple sub-bullets containing the relevant grounds and backing.

5. *Be specific:* While they should be terse, make sure that the elements in your checklist are very dense and specific. The goal is to prepare something that can be expanded with minimal effort into the full written paper.

6. *Be mindful of section-specific details:* Results and Discussion sections start with a restatement of the objective(s) of the study, Conclusions start with a summary of the success of the study, etc.

6.5.2 Where does it belong?

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

- First, make sure that your *Supporting Information*[1] 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 the supporting information comes at the end of a paper, it is the first thing that you'll prepare. You should not include your whole supporting information in your checklist – only include the exhibits that are relevant to the argument.

- Other than in the Supporting Information, sample calculations should not be found anywhere else in your papers. Additionally, raw data will not be included 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* are the claims that you will make, supported by these exhibits (i.e., grounds) and warrants (discussion of the chemical principles that underlie the results and the implications of these results).

- Every exhibit that you discuss in the body of your paper needs to be included, but not all exhibits that you prepare should be discussed. Make sure that your Results and Discussion section only includes exhibits and data that are **directly relevant** to the claims you are making. 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 this waste their time, but it also detracts from the strength of the paper. Exhibits that are important for sub-claims are also included in the body of the paper.

6.6 Qualities of a good 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. **Notice** several important features of the checklist at the end of this chapter:

- 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.

[1] 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.

- 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.
- 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.
- Include citations and bibliographical information to indicate the items that were the result of *your research* and, hence, need *citations* to the chemical literature.
- The *Supporting Information* is first! The first place to start when writing a paper is to **fully** work up the data.

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

6.7 End-of-chapter assignment

1. Differences between lab reports and scholarly papers. Based on the information in this chapter:
   (a) List two ways that your Results and Discussions are different in scholarly papers than in lab reports that you've written.
   (b) List two ways that your Conclusion sections will be different in scholarly papers.
2. Revisit the example of the "fire in Metcalf" from chapter 5. Prepare a checklist for an abridged paper based on the GRA that was presented. You will need to add more components than those that were listed.
3. Consider a recent lab that was performed and go through the steps that you would take in preparing a strong argument and the checklist you would use to write a paper:
   (a) Complete your data analysis. Tabulate the data and indicate where in the paper (or Supporting Information) these would be included. List any exhibits (figures or tables) that you prepared in your analysis. What exhibits, if any, would you use in the actual paper? Explain.
   (b) What is the *objective* of the experiment? Suggest a possible *motivation*.
   (c) What claim are you planning to make? How will you qualify this claim? What warrants and backing do you have to support this claim?
   (d) After completing your data analysis and preparing your exhibits, prepare a Graphical Representation of Argument (GRA) for your paper using the questions from Writing Chapter 3 to help your work. It is likely that you will need to do some research in order to answer these questions.
   (e) Prepare a checklist, of the style described above, that you could use to write a strong paper based on your GRA. Remember that your goal is to prepare a strong, and well-organized, argument.

Example: Sample Checklist

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

Results and Discussion

- Goal of the experiment is to determine worst soda based on sugar content (state objective)
- Of the sodas analyzed in this study (qualifier), Mountain Dew has a significantly higher sugar content making it the least healthy choice (claim).
- Sugar content in the soda was assessed by gravimetric analysis, and the average sugar content is tabulated (data)
  - Exhibit #1 is a table for soda: average ($\pm s$) density, average ($\pm s$) %w/w sugar.
  - Mountain Dew has twice the sugar of the remaining sodas (30% versus 15%)
  - Average soda sugar content is $20 \pm 5\%$
  - Higher sugar content makes soda less healthy (backing)
  - The difference between the Mountain Dew and the remaining sodas is significant ($p < 0.001$), and so it is the least healthy choice (warrant)
- The method was shown to be reliable by analysis of Fresca (warrant)
  - Fresca has no sugar; reliable if the method shows the same (backing)
  - Exhibit #2 is figure of standard curves for %w/w sucrose vs. density for sugar solutions. (data)
  - Fresca density, after carbonation is removed, is consistent with no sugar
- Complete χ^2 analysis shows consistency with manufacturer claims
  - Even though some beverages had larger deviations than others (counter-claim).
  - Method is reliable: linearity in the curve, R^2 of >> 0.9995 (*) (data)
  - Reason why method works best for some beverages and not others is the other components in the soda – contribute to the density and are not consistent (*) (rebuttal, new claim)

Conclusion

- Method successfully determines %sugar that matched manufacturer's claims (restate claim)
- Broader impact: discontinue drinking Mountain Dew because it is 50% worse than other sodas
- Also, this method is effective for low-cost field evaluations of sugar solutions (secondary claim, future directions)

CHAPTER 7

CONVENTIONS OF SCIENTIFIC WRITING

7.1 What to avoid in scientific writing

Having discussed the general type of writing that we will be doing, polished our use of exhibits, and outlined our paper with a GRA and a checklist, we are now ready to begin writing our scholarly papers (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: *inappropriate words*, such as gonna, y'all, or ain't; *idiomatic phrases*, like "since the dawn of time" or "as blind as a bat;" *aphorisms*, iconic sayings, like "there's more than one way to skin a cat;" and *profanity* are all inappropriate in scientific writing. Additionally, make sure to avoid personifications of chemicals, equipment, and results; never use phrases like "tells us", "prefers", "says", "wants to be", or similar anthropomorphizations. These turns of phrase, while appropriate in other forms of writing, must not be used in scientific or technical writing.

2. 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."

3. Avoid using inappropriate or made-up words and phrases. Students new to science, and science writing, almost always make the same mistake: they use inappropriate terms and phrases in their writing. Sometimes it is just that they are using a term that sounds like it should exist (e.g., "massing" is not thing). Other times they conflate terms or use different things interchangeably. 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. In either case, it is important to choose the most appropriate words when writing in the sciences – words that are (nearly) synonymous in other forms of writing can often have very different meanings in science.

4. Never use direct quotes. While direct quotes are common in writing in the humanities, they are almost never used in the sciences, unless you are writing a paper directly critizing a previously published paper. 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. That said, always cite the sources that you used in researching and preparing your paper.

5. 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. Do not embellish in technical writing.

Example 7.1: Overly General Statements

Incorrect: "Potassium Aluminum Sulfate 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 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.

6. 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 statement with appropriate references. In general, statements of previously-known scientific fact that are necessary to support your warrants should be supported by references to authoritative sources.

Example 7.2: Anecdotal and general statements

Incorrect: "Despite this lack of confidence, the consumption of vitamin supplements is very widespread."

Correct: "Recent reports[1−3] indicate 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.

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. Avoid being repetitive or indirect in your writing. Make sure that your paper has a logical flow. Plan your argument with a GRA and then a checklist, and make sure that your argument presents strong and compelling warrants first. Say what you intend in a direct and clear manner. Use GRAs and checklists to organize your writing before you start, and make sure that the points you want to make are complete. Avoid repeating the same points or details, except where it is stylistically required – such as summarizing the outcome at the beginning of a Conclusion or restating the objective at the beginning of the Results and Discussion. Finally, use references to the literature in order to give readers a place to go for more detail and background.

9. Avoid overly complicated words and phrases. When new students start reading scientific papers, 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. Avoid contractions, and spell out the full words.

10. Each thought should be complete, compelling, and well-researched. Do not combine unrelated thoughts in the same paragraph, let alone the same sentence. Also, do not make trite or unsubstantiated statements. Finally, remember that the values and math are meaningless alone; these are only brought to support your reasoning and exposition.

7.2 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 paper 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 analyzing your data, preparing any important exhibits, preparing a GRA, and outlining a detailed checklist for your paper. 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 some non-science disciplines, but it is a terrible idea in science. Starting by sketching out your paper in a GRA and a checklist means that you are more likely to make a convincing argument that follows a logical flow.

2. Make appropriate claims. Don't try to oversell your results. Make sure that the claims you make are supported by your data, consistent with the design and objectives of your experiment, and reasonable in relation to similar, peer-reviewed results.

3. Engage with previous scientific studies and sources. 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 supported by well-researched warrants (from primary sources) in addition to the experimental evidence. Failure to cite these sources, in addition to being a dishonest practice, results in a poor foundation and weak scaffolding for your argument.

4. Each section needs to stand alone. Experts rarely read papers from beginning to end. Frankly, most experts start by looking at the exhibits (and the figure captions) and, in many instances, stop there. If an interested reader decides to "read the paper," they may not read all the sections, or read them out of order. What this means is that *every section of a scholarly research paper needs to stand alone*, without the need for the reader to have read other sections. For instance, a Results and Discussion section always starts by repeating – in no more than one sentence – the objective of the experiment.

5. Less is more, especially when it comes to data. Flooding your reader with unnecessary data, figures, and tables, can only lead to one thing: confusion. Only show appropriate exhibits that *need* 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 will not present it. Using GRAs and checklists to outline your work will save you time in the long run and help you to execute a successful paper.

6. 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 future directions are ...' This just won't read well. Try not to be too "on the nose" with your writing. Instead, try to make sure that your paper has a natural and smooth flow. Just make your claims, and discuss your results, without unnecessarily calling attention to each component by name.

Example 7.3: 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 likely the presence of bisulfite contamination."

Correct: "Managanometric titrations of compound **1** suggest a 46 ± 7% 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.

7. 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. This is a veneer on top of the actual argument, but it is necessary in order to get your work accepted and published.

8. 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 to 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?

9. Most importantly: less is more. This cannot be overemphasized. Length has no correlation with quality, though it can have an inverse relationship at times. On the contrary, overly verbose rhetoric is unacceptable in scientific writing. Readers are not fooled by overly verbose, unnecessarily long papers. The most successful papers are concise, direct, well-reasoned, scientifically correct, and well-organized. Use GRAs and checklists to help prepare your writing tasks and make the strongest argument possible.

7.3 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 novice (science) 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 papers**! 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!

7.3.1 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 among novice writers. This list is by no means exhaustive, but should serve as a 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. It is also worth noting that it is appropriate to avoid the use of contractions altogether in formal, technical writing.
- **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 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. Used correctly, 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 more common that the word **data** is 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). It is best to train yourself to use the proper, plural form of *data*.
- **Significant**: when used in scientific writing, *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 trying 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 a 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*.
- **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 doesn't 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 7.1.

Table 7.1: 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 50 mL was needed*" instead of "*over 50 mL was needed*"
	fewer vs. **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 10 mL*")
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/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.*"

7.3.2 Words that aren't actually words

For novices, knowing and using the proper term for something can often be challenging. In an effort to sound more scientific, well-meaning novices tend to invent words and phrases that just do not exist. Here are a few of the more common made-up terms that creep into student writing.

- *Filtrated.* Filtration is the process by which samples are filtered.
- *Massed.* There is no verb for the process of determining the mass of a substance. Technically speaking, weighed is not the rigorously-correct term, since it is not the weight that is being mea-

sured (though many people do use "weighed"). The good news is that it is rarely necessary to mention that the mass of something was measured – just report it, if it is relevant!

- *Balanced.* Chemical equations are balanced, but I think that students who write "balanced" are referring to measuring the mass of something on a balance. See "massed" above.

- *Put through.* Unless you are writing about a needle and thread, this is probably inappropriate. Samples are not "put through" or "run through" a spectrometer. Spectral data are recorded. That said, we do "run" electrophoresis gels.

While this list is far from exhaustive, it gives you a sense for some of the more common mistakes. For good ways to describe these things, look at the phrases used in your textbooks, lab manuals, and the papers that you read. The more scientific papers that you read, the more you will start to develop a good sense for the voice and vocabulary that is expected. The articles that you've researched to help form your argument are a great place to start.

7.3.3 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 word 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, but 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*."

7.3.4 Sentence construction and word order

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

- **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 7.4: 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.

- **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, but related, sentences to help ideas move smoothly.

- **Double Negatives.** While double negatives are sometimes used as a stylistic nuance to indicate an understated affirmation, they are considered improper in scientific writing.

Example 7.5: 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.

- **Commas.** 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 7.6: Oxford 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.

- **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 7.7: Split 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.

– **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 to check that if you deleted the clause, that the sentence would still make the intended point to the reader or relate the desired information.

Example 7.8: 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 (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 reference to the figure is made concisely.

7.4 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. Three of the more important lessons are (a) that you need to know how people read scientific papers before you can write a good one, (b) that each section of a paper will stand on its own and (c) that experts use an array of tools to assist in their process.

7.4.1 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 chapter). 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. Finding and reading published scientific papers is discussed at length in chapters 3 and 4.

7.4.2 Each section stands alone

As we've mentioned previously, people are usually reading a paper for a very specific purpose: to extract some necessary data (Results), to glean some understanding of an interesting phenomenon (Discussion), to learn how to perform a specific approach or procedure (Experimental/Methods), or to keep on top of the newest innovations in the field (Abstracts, Figures, Conclusion). 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 in the context of the motivation. 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 exhibit is being discussed.

7.4.3 Use tools to effectively plan your writing

Experts develop effective tools and devices to help them in their workflow and process. For expert science writers, many of these tools are quite "low-tech" and are easily accessible for novices entering into the field. Consider adopting the use of some of these to help you in your work.

- *Voice note applications* can be very helpful for organizing your thoughts and getting the major points down. Talking out loud, as if to another person, is often the best way to capture ideas as you have them and to refine them. Later, once you've articulated how you want to say something, you can extract the phraseology from the recording. While this may not save you a lot of time (though it can), it definitely reduces the frustration of losing your thoughts or that "perfect way" you thought to say something.

- *Reference managers* are very versatile and powerful ways to keep track of the research you do in the literature. Many of them can keep the actual PDF of the papers you read, manage the annotations and notes you make, allow you to classify papers by topics, and more. While some of these packages can be costly, many free (and yet powerful) options are available. A significant advantage of using reference managers is that most of them can output your references in any established citation formatting. This can save you a lot of time and headache when you go to assemble your references section.

- *A good printer*, or a cheap printer, will allow you to print drafts and partial drafts for editing ease. If you find it cumbersome to edit your work on a screen, try getting an inexpensive printer to print drafts.

- *GRAs and checklists*, while not technology, are two of the most important tools that you can use. Organizing and solidifying your thoughts, before starting to write, is the best way to streamline the writing process.

7.4.4 Don't try to sound technical, and know your audience

Let the science wow your audience, not your verbiage. Unfortunately, many students new to the sciences conflate 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.

That said, 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.

You have to know your audience. It would be completely inappropriate to spend any time in your paper trying to convince your reader that Beer's law is meaningful; if they don't at least know that, then they have no business reading your paper[1]. 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 for many years.

7.4.5 Be straightforward about the limitations of your work

One of the hardest things for students to do is to resist the compulsion to rationalize, or ignore, 'bad' outcomes. The results that you obtain in any given experiment are, for better or for worse, what you have to work with. Please refrain from claiming that an unreasonable difference between your results and your expected results is anything other than what it is: an undesirable outcome.

Some people feel that they need to justify getting bad results in order to be persuasive. This is a mistake. 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 the classroom writing that you are doing and real-world scientific communication.

7.4.6 Putting it all together

Improving the quality of your writing is not about getting a good grade in a course (though that is certainly a possible outcome). Rather, avoiding the mistakes and and following the tips discussed in this chapter are about improving the quality of your writing – something that you will need to do for the foreseeable future. That said, if a grader is able to easily read your paper 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.

7.5 End-of-chapter assignment

1. Use the information in section 7.1 to critically analyze each of the following excerpts from actual student papers. For each, indicate what general guidelines have been ignored or 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.

[1] We're assuming that we are writing to an expert, or at least scientific, audience.

(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. Identify the grammar and writing problem(s) with each of the following writing samples. Propose an improved version for each.

   (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.

3. Give a copy of your last abridged paper to a friend in your class (someone that you trust and whom you respect) and get a PDF copy of their paper. Your instructor may provide a sample paper for this process. For each of the following questions, please mark up the PDF directly.

   (a) Identify two things (sentences, paragraphs, etc.) that you feel they did especially well. What about them do you appreciate?

   (b) Identify 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).

4. Preparing an abridged paper for a recent experiment:

   (a) After completing your data analysis, prepare a graphical representation of argument (GRA) to help you plan your paper. Make sure to do enough research to ensure that your argument is based on a solid understanding of the science.

   (b) Prepare a checklist that you will use to write your abridged paper (you should not include Introduction and Experimental sections).

   (c) Based on your GRA and your checklist, use the information in this chapter (and all of the previous chapters) to write an abridged paper (Title, Results and Discussion, Conclusion, References, and Supporting Information) for your most recent lab. Make sure to include your GRA and checklist.

CHAPTER 8

ADDING MOTIVATION – INTRODUCTION SECTIONS

The Introduction section of a scholarly paper can often be overlooked by authors. Focused on the innovation that they are 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.

8.1 Content and Organization

In general, there are three specific components included in the Introduction section of a scholarly paper:

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

   Example 8.1: 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 the third component 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 and think about what might interest them in reading your paper. Remember to cite all of the sources that you consult and apply in your work.

   (c) *Essential Background about the area*: a 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. Rely on citations to direct interested readers to the background that you do not intend to specifically discuss.

Example 8.2: 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 has been adequately introduced by discussing the work already done, the next move of the introduction shifts towards thinking about what still needed to be done before the study discussed in the paper. Here, the author introduces and justifies the need for the body of work in the paper: the *gap* in the current state of knowledge in the field.

   It may be difficult to identify a genuine gap (one that actually exists in the current scientific knowledge) for some of your undergraduate course experiments. How to approach this challenge will be discussed in greater detail later in this chapter.

Example 8.3: 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.

8.2 Format and Style

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 for the Introduction section:

- The Introduction section of a paper should consist almost entirely of prose. A computational paper that involves the derivation of new expressions and formulas will typically also include equations. Results are not presented in the introduction.
- You are writing as scientists, not as undergraduate students. The objective of your study 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. See chapter 1 for more on the differences between educational purpose, lab objective, and motivation.

- 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 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, novices 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 paper 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. Focus on information density, not on length.

8.2.1 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 Example 8.2 – 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 8.4: 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, unless your discipline demands it.

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 ...").

8.2.2 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. It is completely inappropriate to write more than is necessary.

Finding this balance can sometimes be hard for a novice science writer. Recall 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 as a student, you should limit your Introduction to about one page, unless otherwise specified. More importantly, 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, 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.

8.3 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). The argument you will make in the results and discussion section is your forray into adding value to the state of the field that you've just motivated as very important.

It should be noted, however, that in undergraduate coursework we will not really have any true "gaps," with few exceptions. It would be inappropriate to invent a fake gap statement, and so we suggest replacing this component with an *objective statement* for papers not related to inquiry in undergraduate courses.

Example 8.5: Gap versus 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.

8.4 Helpful Tips

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

- Writing the Introduction too early! This section should be written **last**, except for the title and abstract. Having a complete picture of your argument (i.e., your results and discussion) is necessary to make sure that the introduction is focused and relevant. 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).

- 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.

- 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 8.6: 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 about the experimental/methods in the Introduction.

Example 8.7: 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).

8.5 Suggested order for approaching writing a paper

A lot of work and thought go into writing a scholarly paper in the sciences. To help plan your work, consider the following suggested order for approaching your writing tasks:

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 are relevant for this lab and assign them as raw data, processed, or statistic. Indicate where you intend to include these 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?). Settle on the strong, yet qualified, claim that will be the central goal of your paper.

4. What warrants and backing will you need to substantiate your claim? What possible objections might others have to your claim (counter-claims) and how do you intend to rebut them? Prepare a GRA for the Results and Discussion and Conclusion sections. Focus on developing a strong argument based on your thoroughly-researched claims.

5. Based on your GRA, prepare a checklist for the Results and Discussion, Conclusion, and Supporting Information sections. Make sure to remember to add all of the additional necessary components (e.g., starting the results section with a restatement of the objective of the study).

6. Now that you've outlined the main part of your paper, it is time to start thinking about the Introduction. Identify the following components and add them to your checklist: motivation and gap. Consider using a table (like the one below) for your checklist. Notice that the table leaves room for the references that you used for **each** component of the Introduction.

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 checklist to make sure that your paper will make sense and present a strong argument. Does the Introduction that you've planned motivate the argument and claims that you will make in the Results and Discussion? You are now ready to write your paper.

8.6 End-of-chapter assignment

1. Review the major ideas in chapter 7, especially the section on 'What to avoid in scientific writing.' 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. Suggest two items that you will change or eliminate when you write your Introduction sections for scholarly papers. Explain very briefly.

2. Prepare a GRA and checklist for your paper (IRDC – Introduction, Results and Discussion, and Conclusion). **Note:** consider following the suggested order in section 8.5.

3. Use the information in this chapter, the checklist you just constructed, and the details from previous chapters, when writing your paper (IRDC).

CHAPTER 9
SHARING YOUR PROCESS – THE METHODS SECTION

For novices, the Methods section can be very difficult to write well. There needs to be a balance between a good amount of detail and readability, without including details unnecessary for the target audience. The sole purpose of the Methods section of a scientific paper is to convey the exact method by which the experiment was carried out. An appropriately-pitched Methods will omit the details that any novice would know (such as how to take a mass by difference, clean a burette, standardize a reagent, etc.) and provide enough description, observations, and details to sufficiently guide an expert to be able to successfully repeat the experiment.

Additionally, the Methods section can often suffer the most from the problems of bad writing and lack of concision. Make sure to review chapter 7 before starting to write your Methods section.

What's in a name?

You may see this section with different names in different journals: Methods, Methodology, Method (not plural), Experimental, or Materials and Methods to name a few. Here, we use the term "Methods," but keep an eye out for a different name. The reality is that this section conveys the same information regardless of the section title.

9.1 Content and Organization

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

- Exact amounts of reagents are only necessary when they are **specific to the success of the method**. In other words, amounts are included when the desired outcome will not occur if different amounts are used. Otherwise, give ranges of concentrations studied, for example.
- Types and purity of reagents. Avoid using brand names; generic names are more appropriate, unless the specific brand of reagent is necessary for the experiment – this is not likely.
- Descriptions of apparatus that are not standard. Only describe an apparatus if it is not a standard, or well-known, apparatus (an Exhibit may be useful here). 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.), as these are understood from the amounts, precision reported, and context or experience.
- 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").

- Only include hazards and safety concerns that are unique and unpredictable – those that would not be standard protocol or commonly known.
- Avoid making explicit reference to tasks, steps, and items that are so commonplace that any well-prepared practitioner would do them.
- Standard practices would be universally followed are not mentioned at all in the Methods section.

In general, the Methods will not include information that belongs in the Results. The one glaring exception is that synthetic papers will typically include percent yields alongside the methods.

Online experimental sections

Some journals have transitioned to a model where the methods section, including all of the experimental details, is published only online in the Supporting Information.

9.2 Format and Style

The Methods almost always consists solely of prose. Diagrams of rare, or new, apparatus should be included as well and referenced in the text. In rare circumstances, a table can be helpful to minimize unnecessary repetitiveness. Some additional formatting guidelines:

- Methods sections are written as prose describing work performed in the past. Do not use bullets, as this is not a procedure in a lab manual.
- When using an approach that has been previously reported in the literature, cite the source for the procedure and do not repeat the instructions. Do, however, discuss the important variations and adaptations that you have made to those literature procedures.
- Only include observations (e.g., color changes, the observance of a precipitation, etc.) within the procedure when they are relevant or important.

9.2.1 Subsections can be useful

If there are several parts to your study, you might consider using subsections in your Methods section. This practice makes the Methods 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 example 9.1); 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. These subsection titles should be specific, not vague.

In addition, many journals ask that you include certain specific subsections: 'Reagents and Materials' and 'Statistical Methods' (or 'Data Analysis'). The Reagents and Materials section is the first subsection of the Methods and is where all of the pertinent information about the chemicals (from where? standardized?), instruments, and techniques can be found.

Example 9.1: Reagents and Materials

Reagents and Materials. All solvents and reagents were provided by the Boston University Analytical Chemistry stockroom and used as received without further purification. Visible-light spectra were recorded in quartz cuvettes using Cary 60 UV/Vis instruments with readings at 0.15 nm intervals..." The materials and methods subsection gives all of the necessary information for an expert to repeat the experiment.

The Statistical Methods (or Data Analysis) section is where all of the post-processing of the data is discussed. 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. Specific statistical tests, along with the thresholds for significance, will be included here as well.

Not all papers need to include these sections. Using these sections appropriately, however, can make the Methods section substantially easier to read (and write) and less cluttered. Make sure to check the expectations of the journal, or course, for which you are writing.

9.2.2 Voice and Tenses

In the natural sciences, Methods sections are written in the past tense and, oftentimes, in the 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. You will find it useful to review important stylistic guidelines for numbers, values, and prose that are presented in chapter 2.

9.2.3 Length and Depth

The goal of the Methods section is to be sufficiently thorough, without being overly verbose or unnecessarily repetitive. Do not add unnecessary words to make it "sound better"; less is more.

Example 9.2: 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 0.1 M nitric acid to the flask. Water was added to the volumetric flask until the mark. The final solution concentration was found to be 0.05 M."

Correct: "A 100-mL solution 0.05 M in $Fe^{3+}(aq)$ was prepared from $Fe(NO_3)_3(s)$ diluted with 0.1 M HNO_3."

Both of the above statements communicate the exact same procedure. The incorrect version provides way too many details; details that an experienced scientist would certainly know and be able to fill in on their own (i.e., that a balance and volumetric flask were used, the amount of reagents needed, etc.).

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.

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

9.2.4 Identifying Equipment

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

- *Standard (relevant model)* equipment refers to instrumentation where the reliability (i.e., precision resolution, etc.) will vary from model to model (e.g., spectrophotometers, melting point apparatus). This type of equipment will be referred to by make and 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 (stainless-steel temperature probe, ice-ethanol cooling bath), the piece of equipment does not have to be identified by make and model in the paper.

Example 9.3: Equipment (relevant model)

"The absorbances of all solutions were measured at 510 nm on a Cary 60 UV/Vis spectrophotometer (0.1 nm data collection interval) that was blanked with deionized water."

Every scientific instrument is built to different, specific specifications. For UV/Vis spectrophotometers, the resolution of wavelengths, data collection interval, and precision are different between instruments. As a result, it is important to mention the exact make and model of one of these instruments. Notice that this statement concisely describes the spectrophotometric measurements, as well as the relevant parameters: wavelength, blank, and data collection interval.

- *Non-specific* instrumentation includes balances (all), glassware (all), and thermometers. It is clear from the degree of precision reported exactly what is used. It is not necessary to even mention the type of instrument.

Example 9.4: Equipment (non-specific)

"After drying for 2 hr at 100 °C in a drying oven, the final dry mass of plant material was 0.5250 g (85.55% yield)."

Notice that the equipment used for recording the mass is not mentioned. There are two reasons for this: (1) it is proper practice to measure mass using analytical balances when the exact mass is needed – every practitioner would do this; and (2) the four digits of precision that are reported could only have been measured on an analytical balance, which is also something that an expert would know.

- Finally, *novel* equipment is equipment designed specifically for the experiment being presented. For this type of equipment, detailed instructions and a diagram or 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.

9.3 Writing a concise Methods section

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, so you must carefully consider the information you are trying to convey, as well as the audience to whom you are writing.

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

1. *"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.

2. *"Would the level of scientist who was interested in reading and 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 as an undergraduate 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.

Example 9.5: Too Many Details?

Incorrect: "Melted agarose in a 2.4% solution was poured into a casting tray with 9 wells and allowed to solidify. TBE buffer was added to cover the gel, and the samples were added to each well. The samples were loaded by placing the pipette tip into the well, just under the buffer but not poking the bottom of the well."

Correct: "TBE buffer was added to cover a 2.4% agarose gel. A 10-μL aliquot of prepared DNA ladder was added to well 1."

The first version reads like a lab manual for introductory students, but in the past tense. We would expect an expert to know most of the details that are written in the first version, and so they should not be included. The second version isolates the crucial information in a clear and concise manner.

3. *"Does having individual steps 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 9.6: 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 0.1 M $HNO_3(aq)$ 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 0.1 M $HNO_3(aq)$ was added. . . . "

Correct: "***Preparation of samples.*** Tablets were 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 0.1 M HNO_3 were added. . . "

In the first example, the nearly identical procedure was described twice (though the mere act of separating them is already an improvement over a Methods written in one, long section). In the second example, the two preparations are combined.

9.4 Helpful Tips

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

- There must be a space between values and units. Also, numbers less than 1 must have a zero before the decimal point. See chapter 2 for more details on proper formatting of values.

Example 9.7: Units

Incorrect: "A .2021 gram sample of NaCl(s) was added to 15mL of ..."

Correct: "A 0.2021 g sample of NaCl(s) was added to 15 mL ..."

Never spell out units, and there should be a space between 15 and mL.

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

Example 9.8: General versus Specific

Incorrect: "A bromine solution was added to the flask"

Correct: "When 10.00 mL of bromine were added to the reaction flask, the solution immediately turned bright orange."

The first statement lacks quantization and specificity. How much bromine was added? To what flask? What happened when you added it?

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

Example 9.9: Methods versus 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.

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

Example 9.10: 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 version is verbose, clumsy, and unnecessary. The second version correctly, concisely, and properly reports the precise amount of solid used (an expert knows to record mass by difference).

9.5 Typical introductory 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 Methods section of a scholarly paper. Often, they include way too much detail about the work that they've done. As these courses are usually their first foray into real-world Methods science, this is not surprising.

The point of a methods section is so that an *expert* would be able to repeat your work. Unless you are engaged in undergraduate research, or a special topics laboratory course, it stands to reason that the vast majority of the protocols that you are following are fairly standard. If that is the case, it is feasible that an entire "experiment" that you've performed might be reduced to a single sentence or word in a methods section. In some cases, the procedure and details from an introductory level course experiment might never be mentioned at all.

Example 9.11: How Much is Too Much?

To help illustrate, let's consider an example from an experiment that is common in many first-year chemistry courses: titrating weak acids with an indicator. Labs of this nature have two main parts: titrating NaOH solutions with a primary standard (like potassium hydrogen phthalate, KHP) in order to determine the precise concentration and using the standardized NaOH to determine the amount of an unknown weak acid (KHP, for example) in an unknown mixture.

The entire Methods section for such an experiment might read as: "Samples of KHP-containing unknowns were titrated against standardized 0.1 M NaOH to a phenolphthalein endpoint." The 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, number of measurements are not included in the Methods.

Moreover, the above passage would only be included if the standardization was a critical outcome of the experiment – this is not likely. Otherwise, simply writing that a "0.1 M solution of NaOH" was used would suffice, as we would leave it up to the expert reader to know if standardizing the base was imperative. If they deemed it necessary to standardize, they would determine the most appropriate manner to do so from published sources and then proceed to do so.

A good approach for learning the appropriate balance in a Methods section is to look at similar types of papers in published journals and mimick the level of detail and the language used.

9.6 Preparing to write a Methods Section

The Methods 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. It is for this reason that many journals have started to omit experimentals from the papers and relegate them to the online posting only.

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 Methods sections, is to use a chart to help sort out the different subsections that you will use, and determine what details are necessary to include and which details should be omitted. This chart will never be included in your paper, but it is a great tool for parsing the details that you may or may not include.

To illustrate the power of this approach, let's consider an experiment to determine iron content by atomic spectroscopy. A suggested breakdown of part of the Methods section is tabulated as follows:

Subsection:	Necessary Information	Unnecessary Information
Materials and Methods	- Glassware prep for trace metal analysis (soaking, and chelating solution) - Make/model of instrument	- Specific glassware used - Source of chemicals (other than the cereal)
Cereal digestion	- Brand and mass of cereal - Volume of acid (and which acid) - Heat for 30 minutes a low boil - Filter to remove all solids	- Glassware used - Exact concentration of acid - Number of washes - Number of filtrations
Preparing standard addition solutions	- Volumes of digestion - Range of stock concentrations	- Glassware used - Exact Fe stock concentration

9.7 End-of-chapter assignment

1. Consider the following excerpt from a not-so-well-done Methods section:

   To titrate a solution of sodium oxalate: 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, 0.2315g were weighed out. Fifty mL of 4.5 Molar sulfuric acid, 200 mL of distilled water, and the 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 then 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 this chapter, identify at least five issues with the style, format, language, or chemistry of the Methods section excerpt above. For example: .02 should be written as 0.02.

   (b) How much of this information is really necessary to be included in an Methods? Explain your choices briefly.

2. Reproduce the table below and use it as a template for a chart for an Methods for a recent lab. The two special subsections and one additional subsection are shown – use as many subsections as you need or deem necessary.

Subsection:	Necessary Information	Unnecessary Information
Materials and Methods		
Data Analysis		

3. Use the chart that you just constructed when writing your Methods section for the lab you chose.

Part III

Modes of scientific communication

CHAPTER 10

GETTING YOUR WORK FUNDED – RESEARCH PROPOSALS

The previous chapters have all focused on the development of a single form of scientific writing: the journal article. There exists, however, a plethora of different forms of communication that a scientist must master. In this chapter we will learn how to write a Research Proposal. The main goal of a research proposal is to convince someone to give you money. To that end, you will have to be an expert salesperson and convince your audience, usually a panel of experts in the field or a closely-related field, that your body of research is worthwhile.

Traditionally, research proposals can be anywhere from 5–50 pages long, depending on the funding agency and the amount being requested. The proposal is broken down into four parts:

1. Cover letter: typically a single page in which you introduce yourself to the funding agency and introduce the topic.
2. Project Summary: a one or two page summary of the project.
3. Project Description: a complete breakdown of the project that includes the background information, complete enumeration of instrumentation and techniques, timeline for the project, budget, and expected results. This is the component that determines the length of the proposal.
4. References: a complete set of properly-formatted references for the proposal.

10.1 Project Summary

In many ways, the Project Summary is the most important part of any research proposal. The Project Summary has the longest shelf-life of any submitted report or proposal; in fact, the funding agencies will retain the Project Summary, as record of the project, even long after the project has been completed. It is for that reason that the Project Summary must be written as if it were a stand-alone document.

10.1.1 Argument

In the past, your arguments have focused on the results of your experiment and their implications. Your goal was to convince the reader that your results have substantial impact and importance in light of the significance of the research area.

The argument you are trying to make in your proposal is quite different. Instead of putting the results into context, your job is to convince the referees (people that are reviewing your proposal and deciding on funding) that you will make excellent use of their research funds. To do this you will need to (a) demonstrate the importance of the research area; (b) explain your well-thought-out plan that you **will use** when executing the research; and (c) clarify the research outcomes and impact that your work **will have**. Notice the declarative voice – this is deliberate; your proposal should be written with confidence and purpose, with the references and research to back it up.

Consequently, the *argument* that you will write for a proposal will be different than one for a journal article. Use the above-mentioned guidelines while contemplating your arguments.

10.1.2 Content and Organization

The Project Summary has five major components and the first three components are, traditionally, heavily cited:

1. *Introduce Topic:* The proposal should start by introducing the topic of the research project and discussing the general project goals. This should be fairly general (but not vague), as the specific expected outcomes will be discussed later in the proposal.

2. *Emphasize Significance:* After introducing the topic and goals, the overarching significance of the research is discussed. Why is this important? What are you hoping to demonstrate? What effect will this have on the field and on the world? It is very important to be convincing here. Remember: your goal is to elicit carefully-guarded, highly-coveted, and difficult to acquire funds.

3. *Summarize Methods:* This is the most important and, hence, longest component of the proposal. Now that the topic has been thoroughly introduced and motivated, the next step is to summarize the methods that will be used in the context of the goals (aims) of the work.

   Here, methods does not refer to a Methods section of a scholarly paper; rather, it refers to (a) traditional techniques that will be used, (b) non-standard equipment/instrumentation that is needed, and (c) novel approaches/techniques that will be developed for the research project. Also discuss and mention if your work will be some sort of modification or combination of existing techniques, or the extension of previous projects.

   It is important to be very clear and **specific** about how the research will be carried out; this is an integral part of convincing the funding agency that it is worthwhile to invest in your project. That said, you should not turn this into an Experimental or procedure. Include details such as specific approaches (types of samples, species being studied, digestions, sample preparation, sample handling, etc.) and instrumentation; but refrain from giving exact amounts, lists of glassware, and step-by-step experimental details.

   It is helpful to break up each of the goals (aims) of the project and to discuss the approaches involved for each. These are often referred to as **Specific Aims** and are usually part of a standalone, one-page document. The methods attributed to each of the aims should be described.

   Example 10.1: Specific Aim

   > "**Specific aim #1** is to determine the efficiency of green washing machines (GWMs) using a combination of digestion techniques and high-performance liquid chromatography. A series of ten dirty, chocolate-stained sock samples will be digested according to the Villar method[1,2]."

   Notice that the specific goal is identified first, along with the general approaches that will be used. Then, the specifics for these methods are given; enough to give the relevant details of how the work will be carried out, but not so much as to constitute an experimental procedure.

4. *Expected Outcomes:* While the actual results of the research are never known *a priori*, it is important to have a good sense of what the results might be. Often, authors make reference to preliminary data or previous work that is similar to the project. If you already have some preliminary data from your project, this would be a good place to use that work.

5. *Summarize Broader Impacts:* The final portion of the Project Summary is to summarize the broader impact that the results of the research will have on the field and, possibly, the world. It is important that these outcomes relate directly to the motivations, or at least be framed in the context of the motivations already mentioned earlier in the proposal.

   Do not go overboard in suggesting fantastical impacts or those that will remain far into the future, even after the project is complete. An initial framework is to think about why *other* people, aside from you, will think this is an important project.

10.1.3 Format and Style

The project summary always starts with the title of the proposal, the name(s) of the principal investigators (PIs), the institution(s) of the PIs, and the date of the proposal. Some funding agencies assign codes or identifiers to PIs and should be included when relevant.

In general, Project Summaries are no longer than two pages with size-10 font. Spacing and margins are rarely specified in the requirements. In general, project summaries and short proposals are not broken down into subsections.

Many have the good practice of using bold face for the key words that start one of the above components. For instance, "**The goal** of this study..." This practice calls the reader's attention to these components.

10.1.4 Voice and Tenses

Unlike journal articles, which are mostly written in the past tense, Research Proposals are partially in the present tense and part in the future tense. All of the introductory material (components 1 and 2) are written in the present tense, as they discuss the current state of the scientific art. The methods, expected results, and broader impact, are all referring to research that may, or may not, take place – in the future.

Another major difference between journal article writing and proposal writing is with regard to the voice. The vast majority of a journal article is written in the passive voice in order to emphasize that the results obtained are not dependent on the scientist, or research group, involved – anyone would have received the same results. In contrast, in a research proposal only the methods and impacts sections are written in the passive voice (depending on the context, methods can sometimes be in the active voice as well).

The remainder of the proposal is written in the *active voice*. Unlike in a journal article, where the emphasis is on the results of the experiment with the idea being that any competent researcher would achieve the same results, in a proposal you want to emphasize your own involvement in the successful outcome of the research – you don't want a funding agency believing that just anyone could do this research. You want them to believe that it has to be you. Often, this will be highlighted by your background that makes you uniquely qualified to undertake this research.

10.2 References

As discussed in chapter 3, the format of bibliographical information is highly discipline-specific. Your goal is to acquire expert exemplars – in this case, funded research proposals – to learn about the expected style in your discipline. In many fields, the format and expectations for proposals will be the same as for journal articles.

As with journal articles, there is no minimum or maximum number of references that are required for a research proposal. That said, a proposal that is light on sources – meaning, that it does not clearly reference the current state-of-the-art in the field in question – will not make a positive impact on the referees that are evaluating it. Remember, your goal is to convince this panel of scientific experts that you are well-equipped to study this important question. Without demonstrating that expertise, it is hard to make a convincing argument that you should be funded.

It is worth noting that for many funding agencies, even when page limits are imposed for research proposals, the References may not be included in the final page limit. As always, it is important to make sure to double-check the requirements and specifications of the funding agency to which you are submitting your proposal to confirm that this is the case.

10.3 Calls for proposals

In many cases, research proposals are submitted in response to a *call for proposals*. The call will include the details of the types of projects being funded, regulations for submissions, and resources. Successful proposals must be tailored to the area(s) outlined in the call or it is likely that they will be summarily rejected. Often, a *program officer* – one of the representatives of the funding agency – will be available to discuss your ideas and the scope of your proposal. It is always a good idea to try to meet with a program officer before submitting a proposal.

10.4 Helpful Tips

The most common mistakes that people make when writing a research proposal are:

- Starting to write without developing a checklist is a big mistake. The success of the proposal will be determined by the strength of the argument, the merits of the science, and the quality of the writing. It is critical that a good checklist, which is designed to form a good argument, be constructed prior to writing the proposal. A successful checklist contain the details of each component of the Project Summary and will also include references.
- Often, proposals are written in collaboration with other researchers. It is a mistake to simply split up the work for the proposal without first agreeing on a shared vision for the proposal. This inevitably leads to a disjointed proposal and duplication of effort.
- While most reviewers might not focus on them explicitly, improper grammar or frequent typos makes the proposal a more amateurish read. The general feeling that the reviewer gets from reading the proposal can often make the difference between getting funded, or not. Your writing should be professional and polished. Review the important details about technical writing discussed in chapter 7.
- Make sure that the broader impacts are directly related to the significance of the research, as this will help to tie together the whole proposal. Also, be reasonable about your expected impacts. Rarely will a single study, like the ones that you are performing in your undergraduate courses or research, come close to curing disease – so do not imply that in your impacts.
- While it is difficult for first-time proposal writers, it is important to reach an appropriate balance of detail in the specific aims. You want a balance of enough detail so the reviewer understands how the methods will be used to answer your research question, but not so much that they could carry out the experiment themselves.

CHAPTER 11

MAKING AND DELIVERING EFFECTIVE RESEARCH PRESENTATIONS

Presentations, like journal articles, are a vehicle for communicating the results of scientific inquiry – an argument. Before planning to prepare a research presentation, review the material and suggestions in previous chapters on how to approach crafting your argument. Specifically, you will need to make sure that you've completely analyzed all of your data, prepared your exhibits, outlined your argument (chapter 5), and have a clear vision of the message you intend to convey. Like in written papers, the effectiveness of a presentation is limited by the quality and strength of the argument that you intend to make. Consequently, make sure to fully flesh-out the argument of your work before starting to prepare your presentation – this is the only way to ensure that you will end up with a strong, persuasive presentation.

Once you've settled on the argument that you intend to make, you can start to think about organizing your work into a presentation. The content being presented, the organization of the materials, the level of detail presented, the aesthetic quality of the slides, and the prose of the speaker are all important aspects that go into crafting a successful presentation.

The rest of this chapter will be dedicated to principles for crafting and executing an effective research presentation.

11.1 Differences between papers and presentations

There are a few notable differences, beyond the medium, between scholarly papers and research presentations. Understanding these differences will help you to organize a presentation for your work that is effective and compelling. Consider the following:

- **Length:** while most journals do impose limits on the length of the papers that they accept, it is usally the case that there is plenty of room to fully discuss your work without feeling the need to compromise on the length. Conversely, research presentations always have a fixed time into which the talk must fit. On occasion these presentations can be as long as 45 minutes or an hour (e.g., thesis defenses, qualifying exams, or invited seminars or colloquia). Typically, however, the contributed conference presentations that are most common are only slotted to last 20 minutes (including questions). By necessity, that means that your presentation will likely only cover *part* of your work.

- **Depth:** given the time constraints imposed by conferences, it is not only the breadth of your presentation that will need to be limited. Similarly, you will also have to be strategic in how deep you are able to go into any given point in your presentation, in order to fit to the time. Fortunately, the goal of conference presentations is not to be the final authoritative dissemination of your work;

rather, presenting at conferences is meant to help you network in your field, engage in the discourse of science, and get other people interested in your work. Once they're interested, they'll be on the lookout for the full paper that contains all of the pertinent depth and breadth.

- **Organization:** as we've seen, journal articles have a rigid organizational format that starts with an introduction, proceeds to methods, presents results, discusses your claims, and ends with a conclusion. While presentations start and end similarly to papers, the main portion of the talk will have a substantially different organization. Specifically, each outcome is fully discussed with methods, results, and claims all grouped together. Then, time permitting, your talk will move on to the next portion of your study. Effective research presentations do not front-load all of the methods like in a journal article. The goal is to tell a convincing story.
- **Voice:** while research presentations are still formal communication, they often have a more relaxed and casual voice – you are talking to a crowd, not delivering a sermon. The appropriate tenses and moods remain the same as journal articles, but speakers often engage in more familiar rhetoric during research talks.

Despite their differences, journal articles and research presentations do share one very important common goal: to convince your audience of your beliefs based on the work that you've done. To that end, it is important to remember all of the lessons from journal articles as you begin to delve into preparing your talk.

11.2 Ten guidelines for constructing an effective presentation

11.2.1 Think message, not slides

When you start by thinking "what's on slide 1, what's on slide 2," you're in trouble, unless you want to end up with a lot of boring slides that say nothing. Before you start on any slides, figure out the answers to the following questions. Ask yourself: what point do I really want to make to my audience? What message do I want to plant in my audience's brains? Now imagine that message on a billboard. You will make a slide to convey that specific message. Together, these slides will unfold the strong argument that you want to make. Revisit all of the details presented in chapter 5 about making a strong argument.

Example 11.1: Using real headlines for slides

Consider the examples of good and poor points that are presented in Table 11.1. Which kind of presentation would you rather go to? The one that makes some kind of point, or one with no point, no focus and sometimes, no end?

Table 11.1: Examples of good and bad presentation points.

Bad points	**Good points**
Here is method X	Why method X is so good at measuring ...
We used A	Using enzyme A increases efficiency by 78%
Endonucleases	Advantage of endonuclease A is ...

11.2.2 Decide why your audience should care

Brainstorm all the possible reasons your audience should care about your point. Imagine that you are at a conference of others in your field. How can you present your material so that they do not feel that the 15 to 20 minutes they spent listening to your talk was wasted time? Find a reason why the audience members should be interested in your particular topic. This is a lot like the "motivation" of a journal article or communication. Start by brainstorming – asking yourself what interests you about your topic. Brainstorm means "come up with a lot of possible answers." You should have at least three answers written down on a list to ensure you've really thought about your audience. Remember that the broader your reasons, the more people will be interested in your presentation. Consider some examples:

- You are introducing a topic that is not currently discussed or well-known
- You are going to add understanding of X to what is already known
- You have tested and improved on a new methodology that is useful
- You have learned a new property of a material that is interesting
- You are applying a known technique to a new system.

11.2.3 Make points, don't cover topics

Once you have the main message that you want to convey, you can divide your presentation into sections. But instead of thinking of sections as a generic category – such as introduction, history, conclusion – think of all the points you want to make that will contribute to your main message (the one on the billboard). Identifying these points makes a big difference how effective your presentation is at engaging your audience. Note: you're still not writing/making slides at this point! Once you have these sub-points, those slides will practically design themselves. See example 11.2 for ideas of some good sub-points.

Example 11.2: Good sub-points for your talk

Table 11.2: Examples of good and bad sub-points.

Good sub-points	Poor sub-points
Explain the problem and its relevance (what we know and why it matters)	State how you personally became interested in or chose this topic.
Relevant methods and results with analysis	Description of every mL measured
Your important findings and brief analysis of their relevance	Your findings with no analysis
Deeper analysis of the important findings and future development	Conclusion with no take-home message

11.2.4 Tell a story – have a flow

Once you've identified good sub-points, it's time to determine the best sequence for them. Try to imagine what would make the most convincing argument and what would be the most interesting flow for your audience. Doing this well means you avoid having presentations that are just 'one thing after another.' Instead, they will have a compelling thread that ties the whole thing together – a cohesive argument.

Consider the following sequence for your presentation (argument):

1. Start by stating the problem – the motivation behind the study and the gap that you are filling. Also include a brief discussion of the most important prior outcomes that are the basis of the study. This part of your talk should be brief – after all, the good stuff is coming next!

2. Following your introduction, you move into the main portion of your talk: your findings. For each main outcome, you should present the solution to the problem that you have uncovered in your research (results), along with the approaches that you used. Discussion of the methods is more akin to the specific aims from a research proposal (chapter 9) than a Methods section from a paper. Then, thoroughly discuss the outcome and make your claim. If you have multiple findings, repeat this part of each one. This will be the longest portion of your talk.

3. As you begin to conclude, remind the audience of the important findings and their broader impacts (refer back to #1). Suggest possible future research avenues or developments that may come from your research.

4. The last slide should thank the appropriate individuals (advisors, students, and collaborators) and organizations (that provided you with resources or funding). Do not spend more than a few seconds on these acknowledgments.

Notice that this sequence very closely matches the same argument sequence that we've developed for our written work, with only small deviations in the body of the talk.

11.2.5 Get creative

Think of exhibits, metaphors, examples, and analogies as a way to back up your sub-points and make them 'sticky'. Here, sticky means that the sub-point sticks with the audience because it came wrapped up in a story, an image, or an analogy. Sure you have data, and you need that data, but persuasion doesn't depend on logic and data alone (if it did no one would pay $3.50 for a bottle of 'vitamin water'). What images, symbols, or other visuals come to mind that might make a stronger impression than just words?

11.2.6 Prepare a presentation "storyboard"

Okay, now you can think in terms of slides! Create a new PowerPoint file using a layout that includes a title placeholder. Figure out what you want your slides to do and just jot that in the title placeholder – that way, you can see that when you look in the outline tab on the normal view of presentation or when you look at slide sorter. You're not designing slides yet, you're making a flow and checking that each slide has a purpose – a message that the slide is going to communicate.

11.2.7 Put a real headline on each slide

No one word headings – ever. Your heading can be a question or a statement, but it must say something meaningful. For inspiration, look at the newspaper – news, sports, editorials, no matter where you look in a newspaper, headlines make statements. Having slide titles that make a point will make your presentation better than just about everyone else's.

11.2.8 Use the body of the slide to best deliver its message

Ignore your first impulse to have a nice bulleted list of one word items. That might be your second and third impulse too, so resist. Sometimes you do need to use a bulleted list, just like sometimes you need to use Febreeze instead of actually washing your clothes, but it's an emergency measure.

Slides aren't supposed to be your teleprompter, though for some presenters that is what it seems they have become. Slides are supposed to be a visual reinforcement of the speaker's point. They don't have to say everything. In fact, they **should not**. They just have to communicate one message. Under no circumstances should everything that you intend to say be on the slide. The slides are your props, not your prompts or your script.

Maybe you've got an image from your creative period back in step #5 – use that. Or maybe you just want to have a few words on the screen but never write every word you're saying. Whatever will convey that message best – in the quickest, easiest, most impactful way – do that.

Example 11.3: Using real headlines for slides

Let's imagine you're working on a presentation that explains why copper is unique in giving high-temperature superconductivity in layered perovskite oxides. Assuming that you have six slides following the sequence detailed above, your headlines might look like the ones in Table 11.3.

Table 11.3: Examples of good and bad slide headings.

Bad headlines	**Good headlines**
Introduction	Copper in high-T superconductivity
Method	Z method is most accurate for studying Cu superconductivity
Results	Copper shown to exhibit X property under Y condition
Graph of X vs. T	X property increases inversely to heat
Figure 2	X property disappears in the presence of Fe
Conclusion	Y conditions should become standard when creating copper superconductors

11.2.9 Use exhibits effectively

Do not include every graph or table that you produced. Figure out what information is necessary to convince your audience of the point you are making. Make the figures *large and legible*, and only include the relevant information. Your viewer is not going to have time to analyze your tables and graphs in detail, so only present the material that they can absorb in a **1-2 minute** slide. Quickly flipping through several slides of tables or graphs does not help you at all; in fact you will lose your audience. One or two good figures to provide the evidence you need to support your claim is all that you need.

Avoid tables that contain copious data. Remember, there isn't time for your audience to mull over your data at length. That isn't the point of a talk. Your goal is to make a convincing argument, and large amounts of data being lobbed at the audience is more likely to distract and confuse them.

Do not use "AutoShapes" or excess animation; these elements are distracting and take focus away from the presenter and, more importantly, from the science. That said, do not make your slides boring and monochromatic. There is a balance between cheesy and boring.

Add annotations to figures and graphs to highlight important features that you will discuss and draw the audience's attention to them.

11.2.10 Work through sections 11.2.1–11.2.9 again and check the balance

It is important that you make several iterative edits to your presentation. Review rules 1-9 to make sure that you have developed a cogent, organized, and persuasive presentation. Additionally, make sure to review the list of common mistakes (below) as you work through your slides. Make sure that each item (slide, table, figure, list) has something meaningful to add. Tell a story; don't simply cover topics.

Finally, it is crucial that there be a proper balance to your presentation. Make sure to spend the vast majority of the time on the *actual scientific study* the was performed: methods, results, and implications. After all, that's why they've come to hear your talk. It is not necessary, nor appropriate, to spend any substantial amount of time on the motivation (they are already listening to the talk and the results should explain why it's important) and future directions (you haven't done them yet!). For a short (15-20 minute) talk, methods and results/discussion should occupy all but a couple of minutes; longer (45-60 minute) talks will usually spend a little longer discussing motivation.

11.3 Formatting your slides

While a talk is certainly much more than just the slides you are using, it is difficult to deliver an effective presentation without appropriate slides. Unfortunately, the default layouts and fonts in most common software packages (i.e., Microsoft Excel, Google Slides, and Numbers) are *completely* unacceptable. Consider the following guidelines for formatting your slides:

- **Font sizes:** your goal is for your slides to be readable, yet have enough room so that you aren't just flipping endlessly through slides. The words should be large enough to be seen, but not so large as to make the slide four lines. Heading fonts should be between 28 and 32 pt, and body type should be around 22-24 pt font. References at the bottom of the slide should be smaller (12-14 pt).
- **Empty space:** there is a fine line between appropriate slide density and being too cluttered. That said, the default templates tend to have way too much empty space on the slide. In the past, projectors and screens were not reliably calibrated, and so it was necessary to avoid the screen edges. Things have changed, but the software has not. Edit the slide template to move headings to the top-left of the slide, and extend the body of the slide to fit the full screen (leaving only a small margin).
- **Bulleted lists:** your slides should not just be an endless series of bulleted lists. Of course, you most certainly will need to include some lists in your slides. Make sure that lists have at least three points, or find another way to display the information. Similarly, a table should have more than two columns or rows.
- **References:** like in journal articles, cite crucial sources that are brought in support of your exposition. In research talks, however, references are included on the slides on which they are relevant. They are placed at the bottom of the slide and follow the proper discipline-specific reference formatting (see chapter 3). Use a significantly smaller font than the regular text, while still large enough to read, to differentiate between citations and slide text. References must be explicitly mentioned by the presenter.

References versus bibliography slides

The **most common** and **most useful** practice is to include references on the relevant slides. In this way, interested audience members can easily jot down the citation that they are interested in pursuing further after the presentation.

It is worthwhile to note, however, that some disciplines do not include references on the slides themselves, but include a complete bibliography slide at the very end. The drawback to this approach is that it can be difficult – if not impossible – for an audience member to easily extract the reference that they want to pursue.

- **Aesthetic appeal:** it is considered preferable that the slides be appealing, yet professional. Use color wisely, especially if you are trying to emphasize something. Avoid using yellow or green, though: they never show up properly on a large screen. Be mindful of different visual abilities (red/green colorblindness, nearsightedness, etc.). Only use slides with solid backgrounds that are white, beige, or similar colors.
- **Avoid animations:** unnecessary animations on slides or during slide transitions is typically considered unprofessional. Moreover, your audience will tune you out for a few seconds anytime something new appears on a slide or a new slide appears. By the time they start listening again, it is likely that they will have missed important information. Don't waste your precious time, or distract your audience, with flourishes that are not necessary.

  That said, sometimes it is useful to have most of the information shown immediately on a slide, but keep some elements initially hidden to be revealed at some point later during the discussion of the slide. That practice is perfectly acceptable, provided that the mechanism will lead to better understanding and focus on the material.

11.4 Helpful Tips

- Figures and tables should be complete, clear, easy to read, and of high resolution. Make sure to follow the guidelines set forth in chapter 2. You do not need to include captions, but legends and labels need to be legible. Also, do not copy/paste from PDF files, this leads to low-resolution images; rather, include these figures as JPEG, PNG, etc., and then resize. While copying figured directly from Excel can be useful (you can then edit directly in PowerPoint), use caution because the data remains linked to the original spreadsheet.
- For a 15-20 minute talk you should have approximately 8-12 slides (excluding the title slide and the slide at the end with the acknowledgments). Your slides are not your presentation! They accent and provide visual cues for your presentation. **Check the balance of your talk** – don't dwell on trivial aspects.
- No cue cards. Your slides should give you all of the 'cues' that you need. That said, do not memorize and regurgitate a speech. A good presentation will respond to the slides and interact with the audience.
- Dress respectively for presentations. You do not need to wear a suit, but it is important that you be dressed in a way that is respectful and appropriate for an academic or professional setting.
- Always be prepared for questions about things that you present. In general, if you mention something then it is fair game to be questioned. Sometimes you are anticipating certain questions – whether it is because you didn't have enough time in the talk to discuss it at length, or because you anticipate possible objections. In either case, it is very helpful to prepare slides to address likely questions, and have them loaded and ready. Place these slides after your acknowledgments slide in case they are needed.

11.5 End-of-chapter assignment

1. *Outlining your presentation.*
   - Prepare a list of points that you intend to make in your presentation (see section W11.1.1).
   - Prepare a list of sub-points that will become your presentation (see section section W11.1.3). Label them as 'A', 'B', 'C', ..., for reference in subsequent questions.
   - Identify the creative elements (see section W11.1.5) that you intend to use. Assign each element to a sub-point.
   - Organize the sub-points in a logical order of slides, and pick a headline for each slide. Assemble these slides into an outline for your presentation.
2. *Slide-deck for the presentation.* Use the answers to the above and the guidelines provided in this chapter to prepare a well-organized presentation for your research project.