Communicating Science

an introductory guide for conveying scientific information to academic and public audiences

Roy Jensen
Common grammatical considerations

Writing for the reader (page 3)
• Write as if you are talking to the reader.
• Write in a positive and professional tone.
• Write to persuade the reader of your ideas and conclusions.

Strategies for quality writing (page 10)
• Keep the subject and verb close together.
• Put appropriate information in the topic and stress positions.
• Present information in logical progressions.

Common tenses and voices (page 25)
• If something is true today, write it in the present tense.
• If something occurred and is complete, write it in the past tense.
• If something will or should happen, write it in the future tense.
• Endeavor to write in the active voice. It is engaging and easier to read.
• Use the passive voice to put emphasis on the action or when the subject committing the action is unknown.

Minimize the use of nominalizations (page 32)
• Use verbs to convey the desired information.

Other considerations
• subject-verb agreement (page 34)
• parallel grammatical structure (page 37)
• British vs. American English (page 39)

Common revisions (page 42)
As you write and review work, continuously ask yourself:
• What information does this phrase add?
• What other meaning can a reader infer?
• How can I rewrite this sentence to improve its readability?

Formatting common information (page 61)

Formatting scientific information (page 65)
Communicating Science

an introductory guide for conveying scientific information to academic and public audiences

Roy Jensen
Communicating Science: an introductory guide for conveying scientific information to academic and public audiences


Copyright, ©, 2016 by Roy Jensen. All rights reserved.

No part of this resource may be reproduced by any process, converted to another form, stored in a retrieval system, transmitted by any process, or otherwise copied for public or private use without the written permission of the author.

Print edition. This resource provides you with a solid foundation in science communication. Use this resource in all your courses and as a reference guide in your career.

If you have any comments or questions, please use the Contact link on RoguePublishing.ca

Versions of this resource


Library and Archives Canada Cataloguing in Publication

Jensen, Roy, 1971–, author

Communicating Science: an introductory guide for conveying scientific information to academic and public audiences / Roy Jensen.

Second edition

Includes index.

Issued in print and electronic formats.


C2016-900841-X

Printed in North America.

10 9 8 7 6 5 4 3 2
# Contents

**Preface**

**Chapter 1. Fundamentals of communication**

- 1.1 Elements of effective communication
- 1.2 Punctuation
- 1.3 Document structure
- 1.4 Document language
- 1.5 Common revisions
  - Additional resources …

**Chapter 2. Communicating scientific information**

- 2.1 Formatting common information
- 2.2 Formatting scientific information
- 2.3 Copyright and plagiarism
- 2.4 Citations
- 2.5 Presenting scientific data: tables
- 2.6 Presenting scientific data: figures, images, and graphs
- 2.7 An introduction to statistical analysis
  - Additional resources …

**Chapter 3. Fundamentals of learning**

- 3.1 Learning theories
- 3.2 Learning and the brain
- 3.3 Considerations when teaching and learning
- 3.4 Reading for understanding
- 3.5 Effective learning and studying strategies
- 3.6 A process to maximize exam grades
  - Additional resources …

**Chapter 4. Research methodology**

- 4.1 History and evolution of science
- 4.2 The breadth of science
- 4.3 Types of research
- 4.4 Research methods
- 4.5 Academic integrity and research ethics
- 4.6 Conducting an investigative project
- 4.7 Conducting a research project
- 4.8 Research question development
- 4.9 Literature review and analysis
- 4.10 The realities of research
  - Additional resources …
Preface

*Communicating Science* provides undergraduate science and engineering students and new technical writers with a foundation for writing, reviewing, and presenting scientific information: reports, proposals, scholarly articles, essays, theses, scholarly posters, oral presentations, and documents for public audiences.

Somewhat surprisingly, writing guidelines are not uniform throughout the sciences and even vary within a scientific discipline. While many scientific organizations publish professional style guides, these guides are high-level documents written for scientists, authors, editors, and publishers. These guides can overwhelm a new writer. *Communicating Science* consolidates common communication concepts for new science writers. *Communicating Science* is unique in its breadth, exploring a wide array of documents that a science writer may be required to prepare and present and contains extensive sections on peer review and editing. *Communicating Science* provides graduate students and/or professional writers with a solid foundation for using the professional style guides of their chosen career.

*Communicating Science* explores all aspects of preparing quality professional documents and presentations.

**Chapter 1 (Fundamentals of communication)** presents strategies for effective communication of scientific information and reviews grammar and style expectations of academic documents and presentations.

**Chapter 2 (Communicating scientific information)** focuses on the formatting of scientific information, tables, and figures, and expectations when citing information.

**Chapter 3 (Fundamentals of learning)** introduces the constructivist learning model and presents the current understanding of how people learn, how learning changes with increasing knowledge about the subject, and presents strategies for effective teaching and learning.

**Chapter 4 (Research methodology)** presents information on the history of science and the development of the current classification of scientific disciplines. The chapter presents the different types of research, common research methods, and strategies for conducting investigative and research projects.

**Chapter 5 (Documents and presentations)** presents guidelines for producing and formatting documents and presentations commonly required of scientists and academic science writers.
Chapter 6 (Peer review and peer evaluation) presents tools and strategies for engaging in effective peer review and peer evaluation, including strategies for giving and receiving feedback. This chapter emphasizes the importance of such skills in preparing quality documents and presentations.

Appendix A (Review questions) lists questions authors should keep in mind to guide the development of documents and presentations. Reviewers should use these questions when reviewing documents and presentations.

Appendix B (Electronic document preparation) instructs authors on how to use the Microsoft Office® suite of tools to produce professional-quality documents and presentations.

Appendix C (Assignments) presents assignments that build skills, experience, and confidence in preparing and presenting documents. Most assignments can be augmented with peer review and/or peer evaluation.

Appendix D (Assessment rubrics) presents rubrics for evaluating the content, organization, and presentation (if applicable) of laboratory reports, scholarly articles and essays, scholarly posters, and scientific presentations. A rubric for evaluating the reviewer during peer review activities is also included.

While Communicating Science does progress from simple to complex concepts, it is possible (and valuable) to teach the chapters in a different order. For example, applying the concepts in Chapters 1 and 2 to the documents in Chapter 5 results in students concurrently improving their grammar, presentation of scientific information, and their ability to compose scientific documents and presentations. Additionally, teaching the editing and peer review components in Chapter 6 early makes peer review integral to the preparation of documents and presentations.

Students can use Communicating Science throughout their undergraduate program. Depending on the institution and program offerings, there are several ways of integrating Communicating Science into the undergraduate program:

• as the course textbook for a science or technical communication course
• as a resource that is used in many courses from first- to fourth-year
• as a resource for students engaged in undergraduate research

Communicating Science is also a valuable resource for persons entering careers where they are required to prepare quality professional documents and presentations.
Using this resource

To get the most out of this resource, you must apply the techniques herein in your everyday activities. Remain conscious of grammar rules and tenses, and think about how to improve the readability of your work. This will improve your writing style, whether you are composing an email, résumé, or scientific document. Get into the habit of reviewing your work and find colleagues with whom you can review each other’s work. This ensures your final documents and presentations are of the highest quality.

The Additional resources … sections list the resources consulted while preparing each chapter and additional resources that may be relevant for anyone wanting to learn more about a given concept. In some sections, information was adapted directly from other sources, and these resources are cited appropriately.

Acknowledgements

I must express my thanks to the following people who have reviewed this document so that it will be of the most value to you:

Aaron Swanbergson  Dr. Craig MacKinnon  Kate Singh-Morris
Audrey Habke       Dr. Derrick Clive    Dr. Lawrence McGahey
Belinda Ongaro     Erin Dul           Niall Fink
Caitlin Guzzo      Dr. Hugh Cartwright Dr. Philip Comeau
Caroline Lee       Dr. Julie B. Ealy    Dr. Umesh Parshotam

I am especially indebted to Sarah-Nelle Jackson for her assistance with Chapter 1 and with editing of the entire document.

A final thanks goes to Dr. Jeremy Tatum. Dr. Tatum sparked my interest in science communication as he was identifying grammatical and style errors in my dissertation … it is amazing where interests begin.

Comments and suggestions to improve this document are appreciated!

Roy Jensen

Offer me a choice between two entrants, [both curious about science, motivated, and ambitious.] One has inadequate chemistry but good literacy skills, the other the converse. Which do I feel has the greater chance of succeeding in a science degree and beyond? Well, I shall take the literate one. Those who disagree with me are quite welcome to the other. — Peter Towns
Chapter 1. Fundamentals of communication

Communication is a critical part of existence. We communicate with our families, friends, co-workers, clients, and with strangers. Verbal and non-verbal communication are the dominant forms of communication with those around us. Written communication is the dominant form with those distant from us and used to create lasting records. Meetings and discussions are often followed-up with a written document detailing the topics and decisions. Being able to prepare these documents is critical to success in your education, career, and personal life, and is the focus of Communicating Science.

In science, the goal is to unambiguously convey accurate and detailed technical information to others, including others whose first language is not English. Spelling errors, grammatical errors, and the phrasing of your prose may cause readers to misinterpret the information you intend to convey, question the quality of the science you conducted, and question your abilities in general. When applying for employment, the decision to interview you is based primarily on your written application.

Improving your writing skills also improves your thinking skills by forcing you to think logically and critically, which makes you a better and more effective communicator. Furthermore, communication is bidirectional: being an effective communicator increases your ability to comprehend what is communicated to you.

Figure 1.1  The components of effective communication.
1.1 Elements of effective communication

A critical component of any communication is that there must be content (information) to communicate. Without content, you are saying nothing and the reader and/or audience quickly realizes that. Once you have information to communicate, convey it with clarity, coherence, concision, and precision so the reader obtains the greatest possible knowledge from the information you share.

**Clarity** refers to clear and unambiguous prose that is suited to the reading level and the background of the reader. The reader should obtain the desired understanding without having to reread sections of the document.

**Coherence** refers to organization and structure that presents information in a logical order.

**Concision** refers to brief but complete prose. The writer conveys the information in as few words as possible, without repetition. Include information that relates to the topic and exclude extraneous information.

**Precision** refers to the selection and use of the correct words to convey the information and obtain the desired understanding.

Another definition of precision pertains to uncertainty in scientific measurement. This second definition is used later in *Communicating Science* when discussing data analysis.
Literary and academic works

**Literary works** include novels, short stories, poetry, plays, and movies. Literary works are valued for their subtlety, multiple interpretations, and ability to excite the reader’s imagination.

**Academic works** include non-fiction books, encyclopedia articles, news articles, reports, theses, scholarly articles, presentations, and documentaries. Academic works are valued for their accuracy, focused singular message, and ability to interest and engage the reader.

You practice and hone the skills of composing literary and academic works by preparing these works and by reviewing the works of others. However, students and scientists have, historically, had limited instruction in preparing academic works.

Like literary works, academic works must interest the reader so that they want to know the complete story — not the fictional story of a literary work — but the factual story of your research/investigative project. Your academic work must

- be truthful (no false or fabricated information)
- be focused on your topic (no extraneous information)
- flow smoothly and logically from idea to idea
- interest and engage the reader

Scientific academic works commonly answer four questions:

1. Why was research conducted? (background, introduction)
2. What research was conducted? (research question, method)
3. What knowledge was gained? (results, discussion, conclusion)
4. What more can be done? (future work)

Answering Question 1 explores the limitations or inconsistencies in the existing knowledge, which sets the stage for a research/investigative project (Question 2). Answering Question 3 explains what was done and how it improves and expands our understanding in this scientific field. Since advancements in science are incremental, Question 4 proposes a course of action to continue the work.

Strategies on how to effectively read academic works are presented in section 3.4.

---

*Work* is a general term that includes written documents and presentations. See section 2.3 for details.
Writing for the reader

When writing, always consider the readers:
- Who are the intended readers?
- What information are readers interested in?
- What foundational knowledge do readers have?
- How can you keep readers interested and engaged?

Once you have these answers, you can produce a coherent document that conveys the desired information to the reader in a clear and concise manner. Common strategies to interest and engage the reader include
- writing at the level of the reader
- writing as if you are talking to the reader
- writing in a positive and professional tone
- writing to persuade the reader of your ideas and conclusions

A common error of science writers is assuming that readers have more knowledge than they actually do. Scientists are often surprised to learn how little scientific knowledge the public actually has, and struggle to convey information using terms understood by the public. You may have experienced this if you have tutored someone in math or science: you were surprised when the tutee did not know something that “everyone knew” and were even more surprised when the tutee struggled to learn that concept.

  Tutor: “Don’t you know the order of mathematical operations?”

Oral communication is approximately 10 % verbal (the words you are saying), 60 – 80 % non-verbal (the tone and emphasis of your words, your posture, facial expressions, gestures, etc.), and 10 – 30 % your appearance (your hair, clothing, cleanliness, etc.). Written communication loses 90 % of the message, but you must still convey the information and your interest and enthusiasm for the project in the words you choose. The written words must say exactly what you want to communicate. This is especially important because you may be communicating scientific information to readers who do not have the same scientific or cultural background or whose first language is not English.
Since scientific information is complex, you want the prose to be as simple and clear as possible. The following strategies improve the readability of your writing for all readers.

- **Clarity**: use the correct words; use the primary meaning of words; use words appropriate for the audience; use simple tenses; make prose understandable on the first reading; use figures, images, and graphs to facilitate understanding.

- **Coherence**: build a story for the reader; present information when required and in a logical progression; do not make the reader jump to other sections of the document.

- **Concision**: minimize the number of words; ensure every word, sentence, and paragraph adds meaningful information; use simple phrases and sentences; use the active voice wherever possible.

- **Precision**: say exactly what you mean; use correct grammar and style; be numerically exact when possible.

- Define technical terms and abbreviations, and minimize the use of scientific jargon (technical terminology understood only by experts).

> Vagueness, ambiguity, and inability to express clearly and succinctly are intolerable in a scientist. — Peter Towns

**Tone in communication**

**Tone** is the attitude and emotion that you convey in the words you use and the emphasis you apply to those words. When speaking, listeners have both the words and your non-verbal oral cues (pauses, vocal inflections, emphasis) to identify the tone you intend for the information. When reading, readers only have your words and must infer tone from those words.

*It is not what you say; it is how you say it.* — unknown

In literary works, writers set any number of tones: angry, authoritative, condescending, courteous, enthusiastic, exciting, hurt, inviting, playful, patronizing, romantic, sad, sincere, threatening, etc.

Consider the following sentences:

The kites danced in the wind and sun.  (joyful, happy)
The wind and waves raged against the shore.  (scary, dangerous)
The light breeze drifted across the quiet beach.  (tranquil, lonely)
The old house moaned and creaked in the cold wind.  (spooky, isolated)
Depending on whom you are interacting with and why, your tone could be casual (with friends) or formal (with professionals).

<table>
<thead>
<tr>
<th>Casual Questions</th>
<th>Formal Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>How’s it going?</td>
<td>How are you today?</td>
</tr>
<tr>
<td>Why hasn’t the prof returned our midterms?</td>
<td>I wonder why the professor has not returned our exams.</td>
</tr>
<tr>
<td>So, what’s going on here?</td>
<td>What the hell are you doing!?</td>
</tr>
</tbody>
</table>

Readers are exceptionally good at picking up tone from prose. Consider the range of emotions you experience reading well-written novels. Readers expect academic works to convey positive, formal, objective, and confident tones. Together, these qualities embody **professionalism** in the work. If the tone is not what readers like or expect, they will not want to read the work.

Academic writers focus on their work. They dedicate years to investigating and understanding phenomena. When they write, academic writers often focus on the information they want to convey and do not consider the readers. This introduces a range of random tones: authoritarian, condescending, indifferent, and/or patronizing tones are common, and are exactly what the reader does not want to hear and feel. It is critical for academic writers to always consider the reader when writing and to impart positive, formal, objective, and confident tones in their prose.

It is difficult to judge tone when writing. However, by **reading your work aloud**, you will notice the attitude and emotion being conveyed. As you read your work, consider the following:

- What emotions am I feeling as I read and hear this?
- Would I like this information presented to me in this way?
- How could I convey this information better?

**Communicating Science** teaches you to create professional documents and presentations. The examples below should help you establish positive, formal, objective, and confident tones in your prose.

**Positive tone**: express information, even negative information, in a positive light; be polite and courteous.

- Your results are wrong because you did not calculate the ____ correctly. (negative)
- The results are incorrect because of an error calculating the ____. (positive) ✓
**Formal tone:** use proper capitalization and punctuation; write in complete sentences; use words appropriate to the readers; sound natural, as if you are talking with a professional colleague.

- You’ll need to replace the batteries or it’ll die. (casual)
- Replace the batteries so the meter will work for the duration of the experiment. (formal)
- Replace the batteries. (demanding)

**Objective tone:** avoid bias; be honest; do not be swayed by personal or xpublic beliefs; base conclusions and recommendations on facts.

- We do not believe the results because they are not consistent with our expectations. (biased)
- We have reviewed our method and calculations, and now believe that our hypothesis is incorrect. (objective)

**Confident tone:** believe in your research and results; believe in yourself; use clear and concise language to convey information.

- The broken hinge on the instrument may have affected our results. (weak)
- Our results were affected by a broken hinge on the instrument. (confident)

You will agree that I am the best candidate for this position. (arrogant)

Given my education and experience, I am confident I will excel in this position. (confident)

Strategies for creating documents with positive, formal, objective, and confident tones include:

- Write as if you are talking to the reader.
- Use pronouns (I, me, we, us, you, they, them) to connect yourself and the reader to your work, but do not overuse them.
- Read your work aloud as you review it.
- Review your work from the perspective of the reader.
- Envision other ways your prose could be interpreted.
- Have a colleague(s) review it.

When you identify areas with problems, revise your document to negate alternative interpretations and to focus on your intended meaning.

Finally, having the appropriate tone is critical when conveying negative information or preparing correspondence on sensitive or controversial topics.

* People may not remember exactly what you did or what you said, but they will always remember how you made them feel. — Maya Angelou

* Objectivity is a fundamental component of all scientific research.
Quality scientific writing

In 1992, Donald Hayes conducted a quantitative analysis of scientific articles compared with newspaper articles. He discovered that scientific articles contain longer and more complex words and that their complexity increases over time. Hayes proposed this was because science is becoming increasingly detailed and specialized, and the terminology equally so. However, Hayes also found that the sentence and document structure was far from optimal. Scientific articles contained long, complex sentences that were confusing, unclear, and grammatically incorrect.

Why? Often because scientists have little formal training in academic writing. Most scientists develop their writing style from the scientific articles they read and review — which themselves are not well written — thereby perpetuating the cycle of poor writing. Furthermore, some scientists believe they impress others with technical language and complex sentences.

From a more cynical perspective, poor writing can be used to inflate incremental results. Lengthy, impenetrable sentences filled with technical terms, elaborate words, and Latin phrases can be used to suggest that results and research are momentous. The psychological game is that readers who do not understand the prose might assume they are not as intelligent as the scientists who conducted the research and wrote the article. Unfortunately, incomprehensible prose may be ignored by other scientists, hindering the advancement of science. (When reviewing work by others, diligently scrutinize any section of text that is difficult to read.)

Incomprehensible and boring scientific prose has another significant consequence: it perpetuates the perception that science is only for the intellectuals and is unimportant in society. On the contrary, science is increasingly integrated into society; an understanding of science is critical to understanding the world around us.

You can often find quality prose in scientific documents written for public audiences, such as Discover, Nova, and Scientific American.

*When the subject is difficult, simplicity is the only way to treat it.*

— Thomas Jefferson

Science writers must understand and accept that the domain of scientific knowledge is vast. There are an estimated 20,000 active science journals, each publishing hundreds to thousands of articles per year. Every scholarly article adds an important, but minuscule, amount of knowledge to the domain of scientific knowledge.

![Figure 1.4](image)

**Figure 1.4** The contribution of every published scholarly article to the domain of scientific knowledge.
Strategies for quality writing

Dr. George Gopen and Dr. Judith Swan* investigated how people read and found that readers expect new information to be presented in a manner that establishes a context for the information. In this way, the development of

sentences → paragraphs → sections → document

produces a coherent document. A good writer puts information where the reader expects to find it. The following general strategies will improve your prose.†

Keep the subject and verb close together‡

Sentence length increases when communicating complex information. There is a tendency to put all the supporting information close to the subject, thereby separating the subject and verb. Do not do this! Keep the subject and verb close together. By telling the reader what the subject did, the reader has the context for why the supporting information is important.

Original: Scientists at CERN, the world’s largest particle physics laboratory, funded collaboratively by twenty European countries, have announced the detection of the Higgs Boson, which is the final particle proposed by the Standard Model of particle physics.

The subject and verb are separated by a clause that provides additional information on the subject. Readers may be more interested in the subject once they know of its contribution to physics.

Revised: Scientists at CERN have announced the detection of the Higgs Boson, which is the final particle proposed by the Standard Model of particle physics. CERN is the world’s largest particle physics laboratory, funded collaboratively by twenty European countries.

† Sections 1.3 and 1.4 provide specific recommendations to improve your prose.
‡ A sentence is one or more words that express a complete thought. All sentences contain a subject and predicate.
   • The subject (noun or pronoun) is the person or thing doing the action.
   • The predicate (verb) is the action or state of the subject.

More information on sentences is presented in section 1.3.
Put appropriate information in the “topic” and “stress” positions

The topic position is at the beginning of the sentence. The topic position links the sentence to existing knowledge or information previously presented and contextualizes the new information presented later in the sentence.

The stress position is at the end of the sentence. The reader interprets the information in the stress position as important. Put new information that you want to emphasize in the stress position.

**Original**: Accident reconstruction, whereby the events before and during a motor vehicle accident are determined based on physical evidence from the scene, is an application of applied classical physics.

**Revised**: An application of applied classical physics is accident reconstruction, whereby the events before and during a motor vehicle accident are determined based on physical evidence from the scene.

In the original sentence, the reader is unsure of the context surrounding “accident reconstruction” and may expect a more profound ending to the sentence. However, the ending is more general. The revised sentence builds from general to specific and from the known to the unknown.

Present information in logical progressions

A series of sentences related to a single idea form a paragraph. While there are many ways to arrange the ideas in a paragraph, a common format is to have each sentence link to existing knowledge and add new information, with the important idea presented near the end of the paragraph. (See page 22 for details and alternative paragraph formats.)

AB. BC. CD. DE.

In the above pseudo-sentences, the first letter corresponds to existing knowledge or information in the topic position; the second letter corresponds to the new information in the stress position. The four sentences would thus make a paragraph.

Scientists often assume the reader is knowledgeable and can fill in the missing information because the information appears trivial and obvious. While trivial and obvious to the scientist, the missing information may not be obvious to the reader, and coherence in the paragraph is lost.

AB. BC. DE.

In the above pseudo-sentences, C is not used and D is not introduced. Even if the reader does have the knowledge to determine CD, it is taxing and time-consuming to reread a paragraph while trying to deduce what is missing. Readers without this specific knowledge are lost.
Fundamentals of communication

Original: Chemical kinetics is the study of the rates of chemical reactions as a function of concentration and temperature. The many different entities present in food complicate the application of kinetics to cooking. One class of chemical reactions, the Maillard reactions, involves the reaction of amino acids with carbohydrates. Maillard reactions produce the browning and much of the flavor in fried foods such as meat, eggs, and toast. Maillard reactions do not occur in boiled and microwaved food.

In the above paragraph, the phrase that introduces concentration and temperature is irrelevant because neither is mentioned later in the paragraph. Additionally, the paragraph does not explain why Maillard reactions do not occur in boiled and microwaved foods.

Revised: Chemical kinetics is the study of the rates of chemical reactions as a function of concentration and temperature. The many different entities present in food complicate the application of kinetics to cooking. One class of chemical reactions, the Maillard reactions, involves the reaction of amino acids with carbohydrates. Above 140 °C, foods with large quantities of these entities undergo browning, which is the source of much of the flavor in fried foods such as meat, eggs, and toast. Maillard reactions do not occur in boiled and microwaved food because the cooking temperature never exceeds 100 °C.

If the writer is placing information where the reader expects it, the reader perceives greater coherence in the document and is increasingly interested and engaged by the work. Importantly, there is a greater chance that the writer will convey the desired information to the reader.

Deviating from the guidelines

The guidelines presented above are just that: guidelines. The occasional deviation from these guidelines can have profound effects: adding emphasis to key concepts, building suspense and anticipation, drawing the reader into your work, and leading to a memorable conclusion — or completely losing the reader. Be careful!
1.2 Punctuation

Punctuation adds structures to prose to clarify meaning. Below are some common and scientific uses of punctuation.* Section 2.4 explains the unique uses of punctuation in citations.

* *How important is punctuation?* Very! Poor punctuation makes your work difficult, if not impossible, to read. Readers will misinterpret your work. Educated people will question your intelligence and education.

Commas ( , ) indicate a separation of ideas or elements within a sentence. Use a comma

• to separate dependent clauses†
  
  Before starting the experiment, ensure that the detector has cooled to –20 °C. The Large Hadron Collider (LHC), which is on the border between France and Switzerland, is the world’s highest energy particle accelerator.

• before a coordinating conjunction (and, or, but, for, nor, yet, so) that joins independent clauses
  
  There is a linear relationship between absorbance and concentration at low concentration, but the relationship becomes nonlinear at higher concentration.

• to separate items in a series
  
  This course covers kinetics, equilibria, and thermodynamics.

For purposes of clarity, a comma is *required* before the last item in a series, as illustrated by the following example.

> An individual intended to give equal portions of his estate to his three children. His will, however, stated “… to my children Jill, Susan and Mark …” Jill argued that she deserved fifty percent and the other two children deserved twenty-five percent each due to the lack of a comma. Her claim was upheld in court. The court stated that the will should have stated “… to my children Jill, Susan, and Mark …” for each child to receive one-third of the estate. — unknown

* Punctuation marks may have additional specialized uses within scientific disciplines.
  
  † Dependent clauses are clauses that can be removed without changing the meaning of the remaining sentence. Dependant clauses can be at the beginning of the sentence (introductory) or in the middle of a sentence (interrupting).

  Independent clauses are complete sentences, but may be part of a complex sentence.

  See section 1.3 for details.
Fundamentals of communication

Do not use a comma to separate the digits in a large number. Some countries use a comma as the decimal point. Use a space, preferably a *thin space* (see Table 1.2), to separate the digits and minimize confusion.

\[ 299,792,458 \text{ m/s} \rightarrow 299\ 792\ 458 \text{ m/s} \]

**Periods** ( . ) are

- placed at the end of a complete thought (sentence)
- in abbreviations to indicate that a portion of the word(s) has been omitted
  
  Ph.D., M.Sc., Dr.

For abbreviations that are all capitals or spoken as words, omit the periods.

NASA, NORAD, CERN

- used as the decimal point (The period is preferred to the comma, but be aware that some European countries use a comma as the decimal point.)

  The sample was irradiated with 337.1 nm radiation from a nitrogen laser.

**Semicolons** ( ; ) are used to

- join complete sentences to emphasize a close relationship between the sentences, but only if a conjunction is not used to join the sentences
  
  There are many idioms and clichés in the English language; they should not be used in scientific prose.

- separate items in a series when those items contain internal punctuation
  
  The active voice is closer to real speech and closer to natural thought processes; produces shorter, concise sentences; and makes arguments more persuasive.

**Colons** ( : ) are used to

\[ \text{... redacted in preview ...} \]
• separate the hours:minutes:seconds of time
The solar flare was detected at 03:48:51 UT on 18 July 2013.

**Apostrophes** ( ’ ) are used to
• indicate possession
  ◦ singular nouns: add ( ’s )
    The scientist’s prose is impeccable.
    The virus’s mode of infection involves ….
    The EPA’s report on airborne particulates …. (the acronym is treated as a word)
  ◦ plural nouns not ending in ( s ): add ( ’s )
    The mice’s cage was maintained at 18 °C and 40 percent humidity.
  ◦ plural nouns ending in ( s ): add ( ’ )
    The students’ success came because of their hard work and dedication.
    The emissions’ carbon monoxide content exceeded 15 ppm by volume.

• indicate the omission of one or more letters from a word to form a contraction (not commonly used in formal writing)
  I will → I’ll 
  do not → don’t

Apostrophes are often misused. The following examples are all correct and illustrate the different applications of apostrophes.

The scientist’s laboratory. (A single laboratory managed by one scientist.)
The scientist’s laboratories. (Multiple laboratories managed by one scientist.)
The scientists’ laboratory. (A single laboratory managed by multiple scientists.)

**Quotation marks** (“”, ‘’) indicate that the text contained within is a direct quotation. Punctuation associated with the quotation is retained within the quotation marks. When quoting within a quotation, single quotation marks surround the inner quotation. When quoting three or

... redacted in preview ...
**Exclamation marks** ( ! ) indicate extreme emphasis — beyond that available within the words themselves — on a statement. Exclamation marks are *rarely* used in scientific work! A maximum of one sentence in a paragraph should receive an exclamation mark.

**CAUTION:** warming the product above 60 °C causes an explosive decomposition!

**Brackets** ( ( ) , [ ] , <> , {} )

- curved brackets ( ( ) ; also called *parentheses*)
  - contain supplementary information. The text in parentheses may be omitted without affecting the conveyed information. Commas are also used to include supplementary information; it is at your discretion whether to use commas or parentheses, but the use must be consistent throughout the work.
    Ethylenediaminetetraacetic acid (EDTA) removes specific metal ions.
    Ethylenediaminetetraacetic acid, EDTA, removes specific metal ions.
    - are used as a shorthand to denote either singular or plural
      Once the sample(s) is (are) analyzed, …

- square brackets ( [ ] )
  - are used to insert information into direct quotes
    The BBC News Service reported, “A NASA study has found that the continent [Antarctica] is losing around 152 cubic km of ice each year.”
  - represent the concentration of a solution in moles per liter
  - contain citation information in some citation styles

- angle brackets ( < > )
  - are used to contain information that must be inserted by the reader
    <insert example here> ... *redacted in preview* ...
Ellipses ( … ) are used to indicate that text was omitted from a quotation. An ellipsis can also indicate an intentionally unfinished sentence or list. When using an ellipsis, ensure the remaining text retains the original meaning and conveys the desired information.

Style guides differ on whether there should be spaces around ellipses. Whatever you choose, be consistent!

Dashes ( - , – , — )

- The hyphen ( - ) is used to
  - join compound words
    - half-life
    - non-reactive
  - join compound modifiers preceding a noun, which imparts a different meaning than the separate words
    - high-frequency noise
    - second-year mathematics
    - mid-Atlantic trench
    - Bose-Einstein condensate
  - join words that spell numbers
    - Approximately one-quarter of the samples are contaminated.
    - Twenty-eight monitoring stations were set up throughout the forest.
  - represent a negative number
  - hyphenate words at their syllables for spacing within a document

- An en dash ( – , about the width of the letter N) is used to indicate numerical ranges, replacing the word to.
  - Samples 3 – 7 showed signs of degradation after the freezer failed and the samples were at room temperature for over 24 hours.

- An em dash ( — , about the width of the letter M) is used to denote a major break in a sentence. Dashes could be replaced with commas, but

  ... redacted in preview ...
Formatting text

Formatting draws attention to text. A key factor in formatting text is that it must be done sparingly to maintain its effectiveness.

*Italics* are used to emphasize a word or phrase, to introduce new terms, and to identify foreign words not common in English. For example, biologists italicize the Latin names of organisms.

**Bold** and **bold-italics** have no defined use. Headings are commonly bold. *(Communicating Science* uses bold-italics to highlight a word being defined in the sentence.)*

However you choose to use formatting in your work, be consistent and use formatting sparingly.

Additional characters

In addition to the obvious keys on the keyboard, computer fonts (Arial, Helvetica, Times New Roman, Calibri, …) contain hundreds to thousands of additional characters. Most word processing programs have a Character Map to view these characters and insert them into your document. Each character also has a unique Unicode sequence that allows you to insert them without using the Character Map. How this is done depends on the program and the operating system (consult the Help menu for instructions). Tables 1.1 and 1.2 present some of the additional characters commonly used in science.

STIX fonts

A consortium of scientific publishers is developing a single comprehensive font set that contains all the fonts used by the scientific
Table 1.1  The characters of the Greek alphabet.

<table>
<thead>
<tr>
<th>Greek alphabet</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
</tr>
<tr>
<td>alpha</td>
</tr>
<tr>
<td>beta</td>
</tr>
<tr>
<td>gamma</td>
</tr>
<tr>
<td>delta</td>
</tr>
<tr>
<td>epsilon*</td>
</tr>
<tr>
<td>zeta</td>
</tr>
<tr>
<td>eta</td>
</tr>
<tr>
<td>theta</td>
</tr>
<tr>
<td>iota</td>
</tr>
<tr>
<td>kappa</td>
</tr>
<tr>
<td>lambda</td>
</tr>
<tr>
<td>mu</td>
</tr>
<tr>
<td>nu</td>
</tr>
<tr>
<td>xi</td>
</tr>
<tr>
<td>omicron</td>
</tr>
<tr>
<td>pi</td>
</tr>
<tr>
<td>rho</td>
</tr>
<tr>
<td>sigma</td>
</tr>
<tr>
<td>tau</td>
</tr>
<tr>
<td>upsilon</td>
</tr>
<tr>
<td>phi*</td>
</tr>
<tr>
<td>chi</td>
</tr>
<tr>
<td>psi</td>
</tr>
<tr>
<td>omega</td>
</tr>
</tbody>
</table>

* There are two common written forms of epsilon and phi.

Table 1.2  Commonly used characters in Times New Roman and Symbol fonts.

<table>
<thead>
<tr>
<th>Selected characters</th>
</tr>
</thead>
<tbody>
<tr>
<td>name</td>
</tr>
<tr>
<td>cents</td>
</tr>
<tr>
<td>Euro currency</td>
</tr>
<tr>
<td>British currency</td>
</tr>
<tr>
<td>open bullet</td>
</tr>
</tbody>
</table>

... redacted in preview ...
1.3 Document structure

Section 1.1 provides general strategies for producing quality scientific prose. The following sections provide specific suggestions for improving your prose.

<table>
<thead>
<tr>
<th>story</th>
<th>DOCUMENT</th>
<th>movie</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>topic</td>
<td>SECTION</td>
<td>setting</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>idea</td>
<td>PARAGRAPH</td>
<td>scene</td>
</tr>
<tr>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>thought</td>
<td>SENTENCE</td>
<td>dialogue</td>
</tr>
</tbody>
</table>

**Figure 1.5** A comparison of the building blocks of a story, academic work, and movie.

**Sentences**

Sentences are the building blocks of prose, with every sentence presenting a single thought. The basic elements of a sentence are the

- **subject (noun or pronoun)**: the person or thing doing the action
- **predicate (verb or verb phrase)**: the action or state of the subject
- **object**: the person or thing receiving the action

\[
\text{Climate change is increasing sea water levels.}
\]

Some sentences omit either the subject or the object if it is obvious what or who is receiving the action. However, most scientific sentences

... redacted in preview ...
**Simple sentences** are independent clauses.

**Compound sentences** are two or more independent clauses joined with a *conjunction*: and, or, but, for, nor, yet, so, ....

**Complex sentences** contain one or more dependent clauses.

- **Simple**: We mixed the chemicals in the beaker. The beaker got warm.

- **Compound**: We mixed the chemicals in the beaker, and the beaker got warm.

- **Complex**: After we mixed the chemicals in the beaker, the beaker got warm.

Short sentences — fewer than ten words in length — are simple and clear, but multiple short sentences result in choppy, abrupt text that is difficult to read. Compound and complex sentences — up to around thirty words in length — are useful for conveying connected information. Sentences over thirty words are difficult to understand and exceedingly difficult to write in a way that accurately and unambiguously conveys information. A good practice is to vary sentence length.

*Original*: Water quality declined in July. The decline occurred because of heavy rainfall. The rainwater washed sediment into the reservoir. The sediment overloaded the water treatment system. Normal water quality was restored in mid-August.

*Revised*: Water quality declined in July because heavy rainfall washed sediment into the reservoir, overloading the water treatment system. Normal water quality was restored in mid-August.

Dependent clauses can be restrictive or nonrestrictive.

**Restrictive clauses** limit or modify the noun in the sentence. Removing the clause changes the meaning of the sentence. Restrictive clauses are not separated from the independent clause by punctuation.

... redacted in preview ...
Recall from section 1.1 that you should put information where the reader expects it:

- The first piece of information in a sentence (in the topic position) should link the sentence to information already presented and contextualize the new information presented later in the sentence.
- The last piece of information in a sentence (in the stress position) contains new information the writer wants to emphasize.

**Paragraphs**

A series of sentences related to a single idea forms a paragraph. There are usually between four and eight sentences per paragraph. One sentence in the paragraph — the topic sentence — expresses the essential idea of the paragraph, with the remaining sentences supporting or illustrating the topic sentence or linking it with the remainder of the document. The topic sentence can be anywhere in the paragraph.

One paragraph format has each sentence linking to existing knowledge and adding new information, with the topic sentence near the end of the paragraph. An alternative paragraph format has the topic sentence as the first sentence. The remainder of the paragraph then adds information to support that idea and place it in context of the document.

Experienced writers use both paragraph styles, choosing the style that best conveys information in a clear, concise, and precise manner and maintains cohesion with the remainder of the document. For example, in each of the following sentences, identify the clauses in the topic and stress positions, arrange the sentences into a coherent paragraph, and identify the topic sentence of the paragraph.

... redacted in preview ...
Getting the reader to follow your logic is challenging, but critical to producing a clear and coherent document. Simply stating fact after fact does not interest, engage, or retain the reader. To do these things, you must

- properly structure sentences and paragraphs
- properly punctuate compound and complex sentences
- use advanced punctuation — colons, semi-colons, dashes — to inform the reader of connections between information
- write at the level of the reader: start with their existing knowledge and build their understanding

To help the reader follow your logic, use words that indicate relationships between ideas. Table 1.3 presents a selection of relationships and words that build relationships.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Selected transition words</th>
</tr>
</thead>
<tbody>
<tr>
<td>add supporting ideas and information</td>
<td>additionally, again, also, as well, equally important,</td>
</tr>
<tr>
<td></td>
<td>furthermore, in fact, in addition, indeed, moreover, similarly</td>
</tr>
<tr>
<td>identify conditions</td>
<td>considering, for the most part, generally, granted, if,</td>
</tr>
<tr>
<td></td>
<td>occasionally, often, ordinarily, rarely, sometimes, usually</td>
</tr>
<tr>
<td>introduce opposing ideas and information</td>
<td>although, but, conversely, despite, however, in contrast,</td>
</tr>
<tr>
<td></td>
<td>nevertheless, on the contrary, still, whereas, while, yet</td>
</tr>
<tr>
<td>show time, sequence, and causation</td>
<td>first, second, before, after, as a result, because, consequently,</td>
</tr>
<tr>
<td></td>
<td>finally, hence, next, since, subsequently, therefore, then, thus</td>
</tr>
<tr>
<td>provide emphasis</td>
<td>certainly, essentially, in fact, importantly, in particular,</td>
</tr>
<tr>
<td></td>
<td>notably, particularly, primarily, significantly, specifically</td>
</tr>
</tbody>
</table>

... redacted in preview ...
Sections

Sentences flow logically from one to the next until an entire idea is presented in a paragraph. Paragraphs flow logically from one to the next until an entire topic is presented in a section. However, there can be significant discontinuity between sections.

In laboratory reports, common sections include the Introduction, Materials, Procedure, Results, Discussion, and Conclusion. These sections present important, but distinct, information that together forms the complete report. In Communicating Science, the chapters are sections and the numbered headings are subsections within the chapters. These subsections present distinct information that together conveys the complete topic. The chapters present a complete introductory guide to communicating science.

Section headings

Every section starts with a heading. Traditional headings are as stated above: Introduction, Materials, ..., Conclusion. These headings are general, providing little information on the contents. Scientific writing is currently transitioning towards headings that are specific, substantive, and that provide information on the section contents.

Procedure → Setup and operation of the __________
Results and discussion → Analysis of the ______ data

While I recommend that you use specific, meaningful headings in your documents, you must conform to the requirements of instructors, employers, and publishers in work you prepare for them. You may find that you have more freedom in using descriptive headings when preparing project reports, essays, posters, and oral presentations, but have

... redacted in preview ...
1.4 Document language

This subsection presents strategies to prepare interesting and engaging scientific prose. In the process, reasons why scientific prose is perceived as abstract, vague, difficult, and tedious to read are identified.

Scientific terms

Many words have defined scientific meanings that differ from common usage. Only use these words in their scientific context when preparing scientific works.

abstract: a summary of a scientific work
aerosol: a small particle dispersed in air (for example, smoke and fog)
bias: a systematic deviation (statistics); constant current or voltage offset (electronics); a preference or prejudice towards a certain result (academic integrity)
confidence level: a measure of the reliability of a result
data: scientific observations that have been collected and recorded
error: a difference between the measured and expected value; range of acceptable values at a certain confidence level (also uncertainty)
fact: an observation that has been repeatedly confirmed and is accepted as true
hypothesis: a proposed and testable explanation of an observed phenomenon
investigation: an exploration of existing knowledge
law: a concise statement that describes the relationship between phenomena
mass: the amount of matter in a body
mean: a calculation of the average
model: a simplified representation of a complex system; a simulation
opinion: a belief based on scientific reasoning
organic: a carbon-containing molecular entity
proof: evidence and results that support a hypothesis (experimental science); the derivation of a mathematical equation or logical statement (mathematics)
radiation: energy in the form of high-energy subatomic particles or electromagnetic radiation

... redacted in preview ...
Grammatical tenses, aspects, and moods

Most native English speakers write reasonable sentences without understanding the grammatical foundations of sentences. This section introduces grammatical tenses, aspects, and moods to build these foundations and to help others whose first language is not English.

There are three tenses and four aspects in the English language. The tense indicates when an action occurred. The aspect indicates how that action relates to the flow of time.

- **simple**: encodes no information about time.
- **perfect**: indicates that the action is complete.
- **progressive**: indicates that the action is continuing.
- **perfect progressive**: indicates that the action is continuing but with a defined completion point.

<table>
<thead>
<tr>
<th>tenses</th>
<th>aspects</th>
<th>simple</th>
<th>perfect</th>
<th>progressive</th>
<th>perfect progressive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past</td>
<td>wrote</td>
<td>had written</td>
<td>was/were writing</td>
<td>had been writing</td>
<td></td>
</tr>
<tr>
<td>Present</td>
<td>write</td>
<td>has/have written</td>
<td>am/are/is writing</td>
<td>has/have been writing</td>
<td></td>
</tr>
<tr>
<td>Future</td>
<td>will write</td>
<td>will have written</td>
<td>will be writing</td>
<td>will have been writing</td>
<td></td>
</tr>
</tbody>
</table>

The mood indicates the type of sentence. Some common English moods are presented below:

- **indicative**: presents factual information.
Grammatical tenses in science writing

If something is true today, write it in the present tense. In scientific documents, much of the Introduction and the Data, Results, Discussion, and Conclusion should be written in the present tense.

This report investigates ....

Figure 3 shows ....

If something occurred and is complete, write it in the past tense. In scientific documents, much of the Methods or Procedure should be written in the past tense.

Einstein’s Special Theory of Relativity, which he published in 1905, proposed that the speed of light is a constant independent of the reference frame of the observer.

◊ “published in 1905” — past tense — done and completed
◊ “the speed of light is a constant” — present tense — correct then and today

The speed of light is exactly 299 792 458 m/s.
The speed of light was defined as an exact value by the CGPM in 1983.

If something should or will happen, write it in the future tense. In scientific documents, some of the Discussion, Conclusion, and Future studies sections should be written in the future tense.

Future experiments will test this hypothesis.

Active and passive voice

The voice is the relationship between a subject and verb.

• active voice: the subject is doing the action. The focus is the subject.
  Students recorded data. Polly wants a cracker.

• passive voice: the subject receives the action of the verb. The focus is ... redacted in preview ...
In many cases, switching between the active and passive voice involves reversing the subject and object or subject and verb.

**Sea water levels are increased by global warming.** *(passive)*

**Global warming is increasing sea water levels.** *(active) ✓*

**Each observation is recorded in your notes.** *(passive)*

**Record each observation in your notes.** *(active) ✓*

Example: given the passive sentence “You are loved by me”, what is the equivalent active sentence?

**Phrases are also active or passive:**

- enthalpy of reaction *(passive)*
- reaction enthalpy *(active) ✓*

The active voice is preferred in most prose. The active voice is engaging, easier to read, and draws the reader into the prose. The active voice best reflects real speech and natural thought processes; produces shorter, concise sentences; and makes arguments more persuasive.

In science, the passive voice was dominant because it presented the science as independent of the scientist.Demanding that students write in the passive voice addressed the problem of over-use of the first-person in the active voice.* However, in the opinion of a growing number of scientists and most academic journals, the active voice is acceptable and valuable in scientific prose. Indeed, numerous prominent scientists — Curie, Darwin, Einstein, Faraday, Feynman, and Watson and Crick —... redacted in preview ...
In general, the passive voice increases confusion, increases text length, and makes writing less lively.

An increase in desertification is predicted by the model. (passive)
The model predicts an increase in desertification. (active)
The model predicts increased desertification. (active)

Essays are written by students. (passive)
Students write essays. (active)

However, there are times when the passive voice is preferred. Choosing the active or passive voice depends on whether the emphasis is on the subject (active) or the object (passive). Use the passive voice

- to put emphasis on the object and action, not the subject committing the action. This is common in Methods and Procedure sections of scientific documents.*
  
The samples were heated to 65 °C for 24 hours.
The glassware was sterilized in an autoclave.

- when the subject committing the action is unknown or unimportant.
  
The equipment was damaged yesterday.
The stock solution was contaminated.

Unfortunately, you may have an instructor, employer, or publisher who insists that you write in the passive voice. Call them an old fogy, but do what they say.

General revisions that change from passive to active voice include

- are/have/is ___ed → ___ (are mixed → mix; is heated → heat)
- x of y → y x (enthalpy of reaction → reaction enthalpy)
- x of a y → y x (activity of a solute → solute activity)
- was/were used to → <delete> (the laser was used to ionize → the laser ionized)

... redacted in preview ...
First, second, and third person

When examining the relationship between the author and the audience, we find that three relationships exist:

- **first person**: the author refers to themselves.
  
  I conducted a finite element analysis of the bridge.

- **second person**: the author refers to the reader.
  
  You conducted a finite element analysis of the bridge.

- **third person**: the author refers to someone or something other than the author or the reader.
  
  They conducted a finite element analysis of the bridge.
  
  Winthrop Engineering conducted a finite element analysis of the bridge.

Table 1.5 lists pronouns used in communicating in the first, second, and third persons. In addition to the third person pronouns, the noun can be explicitly stated as illustrated in the example above, where the third person is “Winthrop Engineering”.

**Table 1.5** Pronouns used to communicate in the first, second, and third person.

<table>
<thead>
<tr>
<th>person:</th>
<th>first</th>
<th>second</th>
<th>third</th>
</tr>
</thead>
<tbody>
<tr>
<td>singular</td>
<td>I, me, my, mine</td>
<td>you, your(s)</td>
<td>he, him, his, she, her(s), it(s), they,* them,* their*</td>
</tr>
<tr>
<td>plural</td>
<td>we, us, our(s)</td>
<td>you, your(s)</td>
<td>they, them, their(s)</td>
</tr>
</tbody>
</table>

* They, them, and their are increasingly being used as a singular gender-neutral pronouns.

A common objection to using the active voice is that it leads to increased use of the first person (I/we) in prose. So? A scientist proposed the ... redacted in preview ...
However, the first and second person can be overused in academic prose. Overuse by new writers occurs when writers are uncomfortable with scientific terminology and/or academic writing. First person is overused when multiple sentences contain I or we, resulting in prose that lacks a professional tone.

*Original:* After confirming the extraction process worked in the laboratory, we were commissioned to build a pilot plant and scale-up the process. I developed the feed and thermal control systems, while Tory designed the monitoring systems and chemical control systems. During the initial pilot tests, Tory observed that the product was not pure, indicating that the extraction was not 100 percent efficient. We are currently trying to determine why this is occurring.

*Revised:* After confirming the extraction process worked in the laboratory, we were commissioned to build a pilot plant and scale-up the process. Feed and chemical control, thermal control, and internal monitoring systems were developed for the plant. Initial tests found contamination of the product stream, and we are currently determining the source of the contamination.

Second person is used minimally since academic works typically inform, not direct, the reader. One exception is instructions and procedures. However, second person references can often be removed or converted to third person without affecting the information being conveyed.

- When tagging salmon, you should know that …. (second person)
- When tagging salmon, one should know that …. (third person)

- Before you enter the laboratory, ensure that your laboratory coat and safety glasses are completely on. (second person)
- Everyone must ensure their laboratory coats and safety glasses are completely on before entering the laboratory. (third person)

Many who argue against the use of active voice and first person argue that the passive voice is objective and impartial. Writing does not make a... redacted in preview...
Nominalizations

A nominalization is the creation of a noun from a verb or adjective. Nominalizations focus the prose on objects and concepts and away from the action and person committing the action. Because of this, nominalizations tend to complement the passive voice. Additionally, nominalization of an important verb obscures the information the writer is trying to convey, which decreases clarity.

Nominalizations are formed by adding a suffix to the verb or adjective. Common suffixes include –ion, –ation, –ing, –ity, –ment, and –ance. Another type of nominalization occurs when the same word is both a verb and noun. Table 1.6 lists common science nominalizations.

<table>
<thead>
<tr>
<th>Verb</th>
<th>Nominalization</th>
<th>Verb</th>
<th>Nominalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>analyze</td>
<td>analysis</td>
<td>observe</td>
<td>observation</td>
</tr>
<tr>
<td>compare</td>
<td>comparison</td>
<td>occur</td>
<td>occurrence</td>
</tr>
<tr>
<td>consider</td>
<td>consideration</td>
<td>perform</td>
<td>performance</td>
</tr>
<tr>
<td>deduce</td>
<td>deduction</td>
<td>prove</td>
<td>proof</td>
</tr>
<tr>
<td>discover</td>
<td>discovery</td>
<td>react</td>
<td>reaction</td>
</tr>
<tr>
<td>dissect</td>
<td>dissection</td>
<td>regulate</td>
<td>regulation</td>
</tr>
<tr>
<td>examine</td>
<td>examination</td>
<td>resist</td>
<td>resistance</td>
</tr>
<tr>
<td>experiment</td>
<td>experiment</td>
<td>report</td>
<td>reporting</td>
</tr>
<tr>
<td>fail</td>
<td>failure</td>
<td>understand</td>
<td>understanding</td>
</tr>
<tr>
<td>grew</td>
<td>growth</td>
<td>vary</td>
<td>variance</td>
</tr>
<tr>
<td>inject</td>
<td>injection</td>
<td>applicable</td>
<td>applicability</td>
</tr>
</tbody>
</table>

... redacted in preview ...

Table 1.6 Nominalization of verbs and adjectives common in scientific prose.
In the first sentence, the important action verb, *to investigate*, is nominalized to the noun *investigation* and the sentence verb becomes the passive *was conducted*. The second sentence is an improvement by using the correct action: *investigate*. However, this sentence is written in the passive voice and does not indicate the subject conducting the action. The third sentence, written in the active voice, presents both the actors and the action.

Considering the above sentences,

• Which was easier to understand on the first reading?
• Which is closest to spoken language?

For most people, the third sentence has the greatest clarity and is closest to spoken language. The third sentence is also the most concise, requiring three fewer words than the first sentence to convey the same information. Having the greatest clarity and concision, the third sentence should characterize your writing.

Nominalizations create a disconnect between structure and meaning: the action is not found in the verb, where readers expect it to be.

\[
\begin{align*}
\text{We performed an analysis of the data.} & \quad \text{(nominalized)} \\
\text{We analyzed the data.} & \quad \text{(active) ✓}
\end{align*}
\]

In the first sentence, the verb is *performed*, but the intended message is that the data was analyzed.

Overuse of nominalizations is another major reason why scientific prose is difficult to read and challenging to comprehend. Indeed, the passive voice and nominalizations together are the two largest contributors to impenetrable scientific prose (and legal and business prose). Observe how the active form is closer to natural speech, clearer, and more concise

... redacted in preview ...
In a few contexts, nominalizations do increase clarity and concision.

• Nominalizations function as transition words, linking successive sentences together. Table 1.3 lists many transition words; some are nominalizations.

  This observation is consistent with our hypothesis. (nominalized) ✓
  We observe that this analysis is consistent with our hypothesis. (active)

• Nominalization of verbs that are not the main action verb better conveys the desired information.

  I do not understand their intentions. (nominalized) ✓
  I do not understand what they intend. (active)

  High-intensity farming has increased the erosion rate and decreased the quality of the remaining soil. (nominalized) ✓
  High-intensity farming has increased the rate soil is eroded and decreased the quality of the remaining soil. (active)

  Erosion, deforestation, desertification, and climate change all contribute to decreasing global food supplies. (nominalized) ✓
  <Active version not reasonably possible.>

• Nominalizations at the end of a sentence provide closure.

  Fertilizer accelerates plant growth. (nominalized) ✓
  Fertilizer helps plants grow faster. (active)

• Some nominalizations have been accepted as common nouns.

  teacher    reaction
  teaching    deviation

**Analogies, similes, and metaphors**

An *analogy* is a comparison made to illustrate the similarities between ... redacted in preview ...
A *simile* is a figure of speech where two things are compared explicitly using terms such as *like* or *as*. These terms indicate that there are limitations in the comparison.

- The eye is like a video camera.
- Carbon fiber fabric is as strong as fiberglass.

A *metaphor* is a figure of speech where one thing *is* a second thing. Metaphors are a stronger comparison than similes.

- Evolution is a game of chance.
- The fog was a thick soup.

In science, analogies and metaphors are commonly used to present new concepts in terms of the reader’s existing knowledge. Scientific models are themselves analogies of a phenomenon.

Conversely, poor analogies introduce misconceptions and create confusion rather than understanding. Readers without the necessary background will be confused, and many metaphors have become clichés (see page 53).

- The comparison of water waves to explain light waves led to the incorrect hypothesis of the *aether*, a medium for the transmission of light.

- Reading the statement “The experiment worked as well as a lead balloon” introduces two possible meanings: when “lead” is interpreted as *forefront*, the reader is confused by the sentence; when “lead” is interpreted as the heavy metal, the reader perceives that the experiment did not work.

- Metaphors comparing the body, world, and universe to a machine necessitated the existence of a creator to build the machines.

*You do not really understand something unless you can explain it to your grandmother.* — Einstein

... redacted in preview ...
Split infinitives

An infinitive is a phrase composed of the word to and a verb.

A split infinitive has an adverb between to and its accompanying verb. The historical rule, based on applying Latin rules to English, has been to not split infinitives. However, this rule is slowly disappearing. Indeed, split infinitives often produce text with greater clarity, coherence, and precision. Split infinitives can also produce text that is more confusing.

The opening sequence to Star Trek contains a well known split infinitive. Placing boldly in any other location does not convey the same meaning.

…to boldly go where no one has gone before. (split infinitive) ✓
…to go boldly where no one has gone before. ✗

We need to really focus on completing the assignment. (split infinitive) ✓
We really need to focus on completing the assignment. ✓

It is difficult to rewrite the following sentences without a split infinitive.

The goal of scientific communication is to unambiguously convey accurate and detailed technical information to others.
The new equipment will more than triple the analysis rate.
The physician asked the patient to gradually decrease their medication.

Subject-verb agreement

There must be agreement between the number of subjects and the singular/plural form of the verb.

The first sample was … Three samples were …
High concentrations of amino acids were … A high concentration of lysine was …

To test for subject-verb agreement, remove all the phrases that separate the subject and verb. With the subject adjacent to the verb, confirm the... redacted in preview ...
Singular and plural Latin and Greek words

Singular Latin words commonly end in –*um*; singular Greek words commonly end in –*on*. The plural of these words ends in –*a*.

- bacterium; bacteria
- medium; media
- phenomenon; phenomena

*E. coli* is the preferred bacterium in microbiology. Bacteria were cultured on agar media. An interesting phenomenon occurs when …

In Latin, *datum* is singular and *data* is plural. However, in everyday use, the meaning of the word *data* is changing. Many scientists now use *data* in both singular and plural contexts.

<table>
<thead>
<tr>
<th>Singular</th>
<th>Plural</th>
</tr>
</thead>
<tbody>
<tr>
<td>The data are reported in Table 3.</td>
<td>The data is reported in Table 3.</td>
</tr>
<tr>
<td>This datum does not fit the linear trend.</td>
<td>This data point does not fit the linear trend.</td>
</tr>
</tbody>
</table>

(traditional) (modern)

From another perspective, the word *data* is becoming like *information*. Information is singular but may represent one fact or many facts.

*Data* is not the only word that has split from its roots:

- *Agenda* (historically plural) now refers to a single list of things to do. *Agendum* is rarely used and *agendas* is commonly used.
- *Criteria* (historically plural) now refers to both one and multiple standards. *Criterion* is still used, but with decreasing frequency.
- *Stadium* is a single sports center. *Stadiums* is used when referring to multiple sports centers. *Stadia* is rarely used.

Parallel grammatical structure

When presenting multiple pieces of information, using the same grammatical structure — *parallel structure* — allows the reader to … redacted in preview …
**Lists**

Presenting information in list form emphasizes the information in the list and is easier to read and follow. If the order of information matters, as in instructions, use a numbered list; otherwise, use a bulleted list. The order of items in a bulleted list should follow a logical progression (preferred), be listed alphabetically, or be in order of increasing line length.

**Materials**
- 500 g sodium carbonate
- 1.0 L concentrated acetic acid
- 1 box of gloves, medium

**Procedure**
1. Go directly to chemistry stores.
2. Obtain required chemicals and equipment.
3. Return directly to the laboratory.

When preparing lists:
- Present the information in the list in parallel structure.
- Omit punctuation in bulleted text unless the text forms one or more complete sentences.
- Do not capitalize the first letter unless it begins a complete sentence or is a proper noun.
Abbreviations, acronyms, and initialisms

An abbreviation is a contracted form of a word.

- Doctor → Dr.
- Master of Science → M.Sc.
- Street → St.
- Doctor of Philosophy → Ph.D.

An acronym is a word formed from the initial letters of the words in a proper noun. While the letters abbreviate several words, the periods are often removed in the acronym.

- NASA → North American Space Administration
- UNESCO → United Nations Education, Scientific, and Cultural Organization

Some acronyms have become so commonly used that they have become common nouns and are not capitalized.

- laser → light amplification by the stimulated emission of radiation
- radar → radio detection and ranging
- scuba → self-contained underwater breathing apparatus

An initialism is a set of letters formed from the initial letters of the words in a proper noun. While an acronym is a spoken word, each letter in an initialism is pronounced separately.

- DVD → digital video disk
- ESA → European Space Agency
- LIF → laser-induced fluorescence
- MS → mass spectrometer
- NMR → nuclear magnetic resonance
- RF → radio frequency
- STM → scanning tunneling microscope
- WHO → World Health Organization

Acronyms and initialisms are common in science. Capitalized acronyms and initialisms should be introduced in parentheses or commas when the... redacted in preview...
**British vs. American English**

The spelling of some words varies between British English and American English as illustrated in Table 1.7. Both spellings are “correct”, although writers, editors, and readers may prefer one spelling.

<table>
<thead>
<tr>
<th>British</th>
<th>American</th>
<th>British</th>
<th>American</th>
<th>British</th>
<th>American</th>
</tr>
</thead>
<tbody>
<tr>
<td>-re</td>
<td>-er</td>
<td>-our</td>
<td>-or</td>
<td>-ae-, -oe-</td>
<td>-e-, -o-</td>
</tr>
<tr>
<td>centimetre</td>
<td>centimeter</td>
<td>armour</td>
<td>armor</td>
<td>archaeology</td>
<td>archeology</td>
</tr>
<tr>
<td>centre</td>
<td>center</td>
<td>behaviour</td>
<td>behavior</td>
<td>gynaecology</td>
<td>gynecology</td>
</tr>
<tr>
<td>fibre</td>
<td>fiber</td>
<td>colour</td>
<td>color</td>
<td>leukaemia</td>
<td>leukemia</td>
</tr>
<tr>
<td>kilometre</td>
<td>kilometer</td>
<td>favourite</td>
<td>favorite</td>
<td>orthopaedic</td>
<td>orthopedic</td>
</tr>
<tr>
<td>litre</td>
<td>liter</td>
<td>flavour</td>
<td>flavor</td>
<td>paediatric</td>
<td>pediatric</td>
</tr>
<tr>
<td>metre</td>
<td>meter</td>
<td>neighbour</td>
<td>neighbor</td>
<td>palaeontology</td>
<td>paleontology</td>
</tr>
<tr>
<td>-se</td>
<td>-ze</td>
<td>-l-</td>
<td>-ll-</td>
<td>-ence</td>
<td>-ense</td>
</tr>
<tr>
<td>analyse</td>
<td>analyze</td>
<td>enrolment</td>
<td>enrollment</td>
<td>defence</td>
<td>defense</td>
</tr>
<tr>
<td>catalyse</td>
<td>catalyze</td>
<td>fulfil</td>
<td>fulfill</td>
<td>licence</td>
<td>license</td>
</tr>
<tr>
<td>colonise</td>
<td>colonize</td>
<td>skillful</td>
<td>skillful</td>
<td>offence</td>
<td>offense</td>
</tr>
<tr>
<td>emphasise</td>
<td>emphasize</td>
<td>-ll-</td>
<td>-l-</td>
<td>-ogue</td>
<td>-og</td>
</tr>
<tr>
<td>organise</td>
<td>organize</td>
<td>counsellor</td>
<td>counselor</td>
<td>analogue</td>
<td>analog</td>
</tr>
<tr>
<td>realise</td>
<td>realize</td>
<td>travelling</td>
<td>traveling</td>
<td>dialogue</td>
<td>dialog</td>
</tr>
</tbody>
</table>

Others:
- ageing vs. aging
- aluminium vs. aluminum
- mould vs. mold
- sulphur vs. sulfur

I suspect you, the reader, have preferences from both British and American English. Writers do as well. It is increasingly common to see ...

... redacted in preview ...
Latin phrases

Latin phrases are more common in older scholarly articles than they are today. They succinctly set the context of the information, but add a barrier to understanding if the reader does not know the Latin phrase. The use of Latin phrases is decreasing, which improves the readability of the work. If you chose to use Latin phrases, punctuate them as the English word.

Table 1.8  Latin phrases common in English prose. When abbreviations are given in parentheses, that abbreviation is used more commonly than the full phase.

<table>
<thead>
<tr>
<th>Latin</th>
<th>English</th>
<th>Latin</th>
<th>English</th>
</tr>
</thead>
<tbody>
<tr>
<td>ad hoc</td>
<td>to a specific task</td>
<td>mea culpa</td>
<td>my fault</td>
</tr>
<tr>
<td>bona fide</td>
<td>genuine; real</td>
<td>non sequitur</td>
<td>it does not follow</td>
</tr>
<tr>
<td>circa (c., ca.)</td>
<td>approximately (time)</td>
<td>per capita</td>
<td>per person</td>
</tr>
<tr>
<td>ergo</td>
<td>therefore</td>
<td>per diem</td>
<td>per day</td>
</tr>
<tr>
<td>et alia (et al.)</td>
<td>and others (people)</td>
<td>per se</td>
<td>by itself; on its own</td>
</tr>
<tr>
<td>et cetera (etc.)</td>
<td>and others (examples)</td>
<td>post mortem</td>
<td>after death</td>
</tr>
<tr>
<td>id est (i.e.)</td>
<td>that is</td>
<td>prima facie</td>
<td>on the face of it</td>
</tr>
<tr>
<td>in situ</td>
<td>in the same place</td>
<td>sic</td>
<td>found in writing</td>
</tr>
<tr>
<td>in utero</td>
<td>in the womb</td>
<td>verbatim</td>
<td>identical; word-for-word</td>
</tr>
<tr>
<td>in vacuo</td>
<td>in a vacuum</td>
<td>vice versa</td>
<td>the positions being reversed</td>
</tr>
<tr>
<td>in vitro</td>
<td>in a test tube</td>
<td>vide infra</td>
<td>see below</td>
</tr>
<tr>
<td>in vivo</td>
<td>in a living organism</td>
<td>vide supra</td>
<td>see above</td>
</tr>
<tr>
<td>inter alia (i.a.)</td>
<td>among other things</td>
<td>videlicet (viz.)</td>
<td>that is to say; namely</td>
</tr>
<tr>
<td>a priori</td>
<td></td>
<td>from the former; from postulates</td>
<td></td>
</tr>
<tr>
<td>ab initio</td>
<td></td>
<td>from the beginning; from first principles</td>
<td></td>
</tr>
<tr>
<td>exempli gratia (e.g.)</td>
<td></td>
<td>for example</td>
<td></td>
</tr>
</tbody>
</table>
1.5 Common revisions

Recall the hallmarks of quality scientific prose: clarity, coherence, concision, and precision. As you write and review work, continuously ask yourself:

• What information does this word/phrase add?
• What other meaning can a reader infer?
• How can I rewrite this sentence to improve its readability?

Below are selected revisions you should consider making to improve the readability of your work. These are only representative revisions meant to prime your mind: as you write and review work, constantly monitor what you are doing to determine how best to convey the information.

*Omit needless words!* — William Strunk, Jr., *The Elements of Style*, 1918

*Write with precision, clarity and economy. Every sentence should convey the exact truth as simply as possible.* — Instructions to Authors, *Ecology*, 1964

**Jargon**

*Jargon* is specialized technical language common to a scientific field, but not commonly used outside that field. The use of jargon introduces a

... redacted in preview ...
Selecting appropriate words and phrases

The goal of scientific communication is to convey information as clearly and concisely as possible. Choose words and phrases so that the audience understands the work. Technical and scientific terms are appropriate for academic audiences, while common terms with similar meanings are more suitable for public audiences. Endeavoring to wow a public audience with highly technical language will have the opposite effect: the audience will not understand what you have written and may feel disdain for you and science. Table 1.9 lists scientific terms and near-equivalent common terms. See also the changes recommended to reduce tautology (page 54) and circumlocution (page 55).

If writing for a diverse audience, write for the simplest audience. Every reader will understand what you have written, and the academic reader interested in your work is usually comfortable contacting you to learn more about your work.

Table 1.9 Terms appropriate for scientific and public audiences.

<table>
<thead>
<tr>
<th>Scientific</th>
<th>Public</th>
<th>Scientific</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>accomplish</td>
<td>do</td>
<td>exhibit</td>
<td>show</td>
</tr>
<tr>
<td>accumulate</td>
<td>gather</td>
<td>fabricate</td>
<td>build</td>
</tr>
<tr>
<td>acquire</td>
<td>get</td>
<td>facilitate</td>
<td>help; simplify</td>
</tr>
<tr>
<td>activate</td>
<td>begin; start</td>
<td>hypothesis</td>
<td>educated guess</td>
</tr>
<tr>
<td>anticipate</td>
<td>expect</td>
<td>implement</td>
<td>begin; start</td>
</tr>
<tr>
<td>assist</td>
<td>help</td>
<td>initialize</td>
<td>start</td>
</tr>
<tr>
<td>commence</td>
<td>begin; start</td>
<td>initiate</td>
<td>begin; start</td>
</tr>
<tr>
<td>concept</td>
<td>topic</td>
<td>modify</td>
<td>change</td>
</tr>
</tbody>
</table>

... redacted in preview ...
Some words have secondary meanings that may introduce ambiguity into the information you wish to convey. You want to use the correct scientific word to convey information. Below are some words that have specific meanings or multiple meanings. They should be used appropriately in your prose. The scientific terms on page 25 must also be used appropriately.

- **angle** → perspective/viewpoint (defined term in mathematics)
- **concludes** → shows/suggests/supports (research cannot prove something to be true)
- **maximize** → increase/higher (are you sure it is a maximum?)
- **minimize** → reduce/lower (are you sure it is a minimum?)
- **proves** → shows/suggests/supports (research cannot prove something to be true)
- **sacrificed** → killed (no ritual implication)
- **significant** → <undefined> (defined term in statistics)
- **spectrum** → <undefined> (defined term in spectroscopy)
- **unique** → <undefined> (are you sure it is truly unique?)
- **weight, mass** (both are defined terms; see page 70)

Additionally, some words have different connotations.

- Some words preferentially apply to one sex.
  - beautiful vs. handsome

- Some words have legal implications.
  - lacks ability vs. incompetent

- Some words have different degrees of formality.
  - puking vs. vomiting vs. emesis

**Contractions**

A **contraction** is a shortened form of a word, substituting the missing letters and words with an apostrophe. Contractions are common in

... redacted in preview ...
Commonly confused words

Affect or effect

*Affect (verb)* means “to act on”, “to influence”, or “to produce a change in”. Use affect if you can substitute alter, modify, move, or transform and the sentence still makes sense.

The wind affected the acceleration rate.

*Effect (noun)* means “the result of” or “the ability to produce results”. Use effect if you can substitute appearance, consequence, or outcome, and the sentence still makes sense.

One effect of climate change is an increase in sea water levels.

*Effect (verb)* means “to cause”, “to bring about”, “to accomplish”, or “to make happen”. Use effect if you can substitute caused, implement, made, or make.

We can effect ripening of bananas with ethylene.

Amount or number or quantity

*Amount* refers to something, usually singular, that is not quantified (water, sand, …) or not quantifiable (work, information, feelings, …).

A large amount of water is required for cooling.

A small amount of light leaked into the detector.

*Number* refers to something, usually plural, that can be quantified.

A large number of samples must be analyzed. (could also use quantity)

The virus infected a small number of computers.

*Quantity* refers to something, either singular or plural, that can be quantified.

... redacted in preview ...
Among or between

Among refers to a collective or group containing many things.
A growing consensus among scientists is that sugar is as great a health risk as fat.
Tianna scored highest among her friends.

Between distinguishes, relates, or compares two or more things.
An agreement was reached between scientists to share data.

Because or since

Because introduces an explanation for an action.
The analysis will take three weeks because of the large quantity of data.

Since is associated with time.
I have been working on this since 2010.

Because of or due to

Because of is an adverb that modifies a verb.
Our field trials were cancelled because of weather.

Due to is an adjective that modifies a noun or pronoun; it is commonly preceded by the verb “to be”. Due to is correct if you can substitute with attributable to, caused by, resulting from, or supposed to, and the sentence still makes sense.
The cancellation was due to weather.
The instruments are due to arrive today.

Can or will

Can means “is capable of”.
Will means “is going to” or “is willing to”.
... redacted in preview ...
Few or less

*Few* refers to objects that can be counted (count nouns).
  few students

*Less* refers to objects measured in bulk (mass nouns).
  less rain

*I* or *Me* (see also *who* or *whom*)

Whether *I* or *Me* is used to identify the first person in a sentence depends on the context of the sentence. If everyone else is removed, which is the appropriate pronoun to use?

- Will you help Jamie, Susan, and me clean the laboratory?
  → Will you help me clean the laboratory?
- Jamie, Susan, and I are cleaning the laboratory.
  → I am cleaning the laboratory.

Formally: *I* is a subjective pronoun and *me* is an objective pronoun.

Imply or infer

*Imply* means “to state indirectly”.

The preliminary report implies that damage was caused by defective material.

*Infer* means “to deduce”.

I infer that we will be analyzing the construction material to identify the defective components.

If something is not stated directly, writers and speakers *imply* it with their prose, while the audience *infers* meaning from their words.

... redacted in preview ...
Loose or lose

*Loose* means “not tight” or “not attached”.
*Lose* means “fail to retain” or “misplace”.

Man or male Woman or female

*Man/woman* are nouns.
The man wearing the gray blazer.

*Male/female* are adjectives.
Female students.

Principal or principle

*Principal* (noun) means “the head or director”, usually of a school;
(adjective) means “highest importance” or “most important” in a
group.
*Principle* (noun) means “a fundamental doctrine, tenet, or truth”.

That or which?

*That* precedes a restrictive clause. Removing the clause changes the
meaning of the sentence.
Test tubes *that have flared ends* cannot be used in the centrifuge.
Test tubes cannot be used in the centrifuge.

*Which* precedes a non-restrictive clause. Removing the clause removes
information, but does not change the meaning of the sentence.
The samples were contaminated, *which resulted in erroneous results*.
The samples were contaminated.

... redacted in preview ...

... redacted in preview ...
**Other commonly confused words**

<table>
<thead>
<tr>
<th>Commonly Confused</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>absorb/adsorb</td>
<td>flammable/inflammable/nonflammable</td>
</tr>
<tr>
<td>accept/except</td>
<td>generally/typically/usually</td>
</tr>
<tr>
<td>adapt/adopt</td>
<td>good/well</td>
</tr>
<tr>
<td>advice/advise</td>
<td>habitable/inhabitable</td>
</tr>
<tr>
<td>ascent/assent</td>
<td>in/within</td>
</tr>
<tr>
<td>assay/essay</td>
<td>lay/lie</td>
</tr>
<tr>
<td>bi_____/semi_____</td>
<td>many/much</td>
</tr>
<tr>
<td>censor/sensor</td>
<td>number of/total of</td>
</tr>
<tr>
<td>centered around/centered on</td>
<td>parameter/perimeter</td>
</tr>
<tr>
<td>cite/sight/site</td>
<td>regardless/irregardless</td>
</tr>
<tr>
<td>complement/compliment</td>
<td>shall/will</td>
</tr>
<tr>
<td>continual/continuous</td>
<td>stationary/stationery</td>
</tr>
<tr>
<td>council/counsel</td>
<td>their/there/they’re</td>
</tr>
<tr>
<td>compose/comprise</td>
<td>to/too/two</td>
</tr>
<tr>
<td>device/devise</td>
<td>translucent/transparent</td>
</tr>
<tr>
<td>elicit/illicit</td>
<td>vial/vile</td>
</tr>
<tr>
<td>emit/omit</td>
<td>your/you’re</td>
</tr>
</tbody>
</table>

**Gender neutrality**

Two strategies to make text gender-neutral are:

- **using a gender neutral term**
  - waiter/waitress → server
  - chairman/chairwoman → chair
  - manned → operated
  - policeman → police officer

- **changing the definition of a term**
  - actor/actress → actor
  - he/she → they
  - guy/gal → guy

The English language does not have a singular gender-neutral personal pronoun. “He/she” or “s/he” are used, but “they” and “their” are increasingly common as both a singular and plural pronoun.
Avoid misplaced modifiers

A modifier affects how another word is interpreted in a sentence. Modifiers must immediately precede or follow the word they modify. Misplacing the modifier introduces ambiguity into the sentence.

Who is eager to begin the experiment: the equipment or the students?
Eager to begin the experiment, the equipment was turned on by students. (error)
Eager to begin the experiment, students turned on the equipment. (correct)

Who is going to the laboratory: they or the three classrooms?
They passed three classrooms on their way to the laboratory room. (error)
On the way to the laboratory, they passed three classrooms. (correct)

Who/what is in pristine condition: the person or the samples?
Being in pristine condition after the trip, I believed the samples were not contaminated. (error)
The samples were in pristine condition after the trip, so I believed they were not contaminated. (correct)

Who is in glass vials: the samples or the students?
The samples were provided to students in glass vials. (error)
Students were provided samples in glass vials. (correct)

Did she say this on Friday? Or is she returning them on Friday?
The instructor said on Friday she would return our exams. (error)
On Friday, the instructor said she would return our exams. (correct)
The instructor said she would return our exams on Friday. (correct)

Several words often cause misplaced modifiers: almost, just, merely, nearly, only, and that.

Did they present or not? ... redacted in preview ...
Avoid multiple adjectives and adverbs

**Adjectives** qualify nouns and pronouns, providing information such as “what kind”, “which one”, and “how many”.

- The automated sampler is very accurate.
- The high-intensity light source saturated the sensitive detector.

**Adverbs** qualify verbs, adjectives, and all other components of a sentence, except nouns and pronouns. Adverbs provide information such as “how”, “when”, and “where”.

- The samples were analyzed immediately after collection.
- Slowly add the acid into water while stirring vigorously.

Try to use only one adjective or adverb to qualify a phrase; more than this and it becomes difficult to determine what is being qualified. If more qualifiers are required, use a dash to separate the qualifiers from the phrase or separate the phrase into multiple sentences.

- chemical healing suppression (error)
- suppression of healing by chemicals (correct)
- chemical healing-suppression (correct)

Matrix ablated molecules were identified by spectroscopic analysis.
- Spectroscopic analysis identified that the ablated matrix was molecular (correct)

Avoid ambiguous pronoun references

A pronoun replaces a noun, but it must be clear what noun it replaces. Common ambiguous pronouns include *they*, *them*, *it*, *this*, *his*, and *her*.

- Does “they” refer to the radio signals or airwaves?
  - Transmitting radio signals by satellite overcomes the... redacted in preview... (error)
Avoid anthropomorphism

*Anthropomorphism* is the attribution of living qualities to inanimate objects. Anthropomorphism is not accepted in scientific prose because it imposes qualities onto objects that the objects do not have. In the extreme, readers may be left with the impression that an inanimate object is conscious of its surroundings, capable of making decisions, and capable of intentional actions.

The data suggests that LDL level and atherosclerosis are linked. Analyzing the data, we discovered a correlation between LDL level and atherosclerosis.

The storm ravaged the coast.
The intense wind, rain, and high waves damaged the coast.

The fire licked the lower tree limbs.
The flame height was at the lower tree limbs

My car refuses to start on cold mornings.
Cold weather prevents my car from starting.
My car does not start on cold mornings.

Avoid double negatives

Readers, especially readers whose first language is not English, often misinterpret double negatives. Writers should remove them in their prose.

Increasingly less common → decreasingly common or increasingly uncommon

Whenever possible, write positive relationships as positives.

It is not uncommon for … → It is common for …

It is not unreasonable to ask everyone to wear laboratory... redacted in preview ...
Avoid clichés and idioms

Clichés and idioms are expressions whose meaning is different from the words used and whose meaning requires the reader to have certain cultural knowledge. They confuse readers who try to interpret these expressions literally and add unnecessary words to prose.

A cliché is an overused expression that has lost its effectiveness. An idiom is an expression whose meaning is not consistent with the words in the expression. There are many idioms and clichés in the English language; they should not be used in scientific prose.

| All other things being equal | (if the assumptions/hypotheses are correct) |
| At the end of the day | (in conclusion) |
| Avoid ____ like the plague | (do not interact with ____) |
| Break new ground | (start a new project) |
| Bite your tongue; put a sock in it | (don’t talk) |
| Blinded by science | (confuse someone with technical information) |
| Blow a fuse | (get angry) |
| Burning the candle at both ends | (working too hard; burning out) |
| Cry wolf | (false alarm) |
| Different ball game | (an unrelated topic) |
| Don’t bite the hand that feeds you | (don’t annoy your parents/boss) |

... redacted in preview ...
monkey business  (questionable actions)  
not rocket science  (not very hard)  
on the same wavelength  (thinking alike)  
shed light on ____  (explain ____)  
the tip of the iceberg  (a small portion of the problem is apparent)  
think outside the box  (devise a creative solution)  
throw ____ under the bus  (get someone else in trouble)  
time is money  (time is valuable, don’t waste it)  
turn a blind eye  (ignore wrongdoing by others)  
you’ve got your wires crossed  (you’ve misunderstood)  
zero tolerance  (all violations, no matter how small, will be punished)  

Avoid tautology

Tautology is the unnecessary repetition or needless clarification of a phrase.

1:30 AM in the morning → 1:30 AM  
amandatory requirement → requirement  
a specific example → an example  
mutual cooperation → cooperation  
absolutely pure → pure  
new innovation → innovation  
alternative choices → choices  
oval in shape → oval  
an integral part → a part  
PAGE gel → PAGE  
are currently in the process of → are  
past experience → experience  
brief summary → summary  
perfectly clear → clear  
collaborate together → collaborate  
PIN number → PIN  
completely surrounded → surrounded  
positive benefits → benefits  
conclusive proof → proof  
previously discovered → discovered  
consensus of opinion → consensus  
quite obvious → obvious  
equal halves → halves  
quite unique → unique  
few in number → few  
red in color → red  
first began → began  
reverted back → reverted  
first priority → priority  
related to each other → related  
fully recognize → recognize  
science of botany → botany  
future plans → plans  
the data in fact shows → the data shows

... redacted in preview ...
Avoid circumlocution

*Circumlocution* is the use of excess words.

- a decreased number of → fewer
- a great deal of → much
- a large number of → many
- absolutely essential → essential
- active consideration → consideration
- afford an opportunity to → allow
- alternative choice → choice
- an increased length of time → longer
- arrive at a decision → decide
- at some time in the future → later
- at the present time → now
- based on the fact that → because
- be cognizant of → know
- be of assistance → assist
- by means of → by/with
- cause injuries to → injure
- cognizant of → aware; know
- come to the conclusion → conclude
- consideration was given → I considered
- conduct an analysis of → analyze
- conducted a study of → studied
- despite the fact that → although
- due to the fact that → because
- during the time that → while
- few in number → fewer
- final outcome → outcome
- firmly commit → commit
- first of all → first
- for the purpose of → for, to
- for the reason that → because, since
- are found to be in agreement → agree
- in other words → thus/hence/therefore
- in regards to → about/regarding
- in respect of → for
- in the event that → if
- in the neighborhood of → about
- in the process of developing → developing
- in view of the fact that → since, because
- is based on → depends on
- it is assumed that → if
- it is often the case that → often
- it is possible that → may
- it may well be that → perhaps
- it should be noted that → note that
- it would appear that → apparently
- longer time period → longer
- made arrangements for → arranged
- made the decision → decided
- make a examination of → examine
- mix together → mix
- most unique → unique
- of the same opinion → agreed
- on a daily/regular basis → daily/regularly
- on account of the fact that → as
- original source → source
- seal off → seal
- separate entities → entities
- small number of → few
- smaller in size → smaller
- spell out in detail → explain
- that have → with
- the fact that → that
- time period → period
- up to the present time → now
- was given → have been given
- was held → have been held
- was made → have been made
- was used → have been used
- were stated → have been stated
- will be given → will have been given
- will be held → will have been held
- will be made → will have been made
- will be used → will have been used
- would be given → would have been given
- would be held → would have been held
- would be made → would have been made
- would be used → would have been used
- would have been given → would be given
- would have been held → would be held
- would have been made → would be made
- would have been used → would be used
- would have given → would give
- would have held → would hold
- would have made → would make
- would have used → would use
- with the fact that → with that
- would it → would
- with respect to the fact that → concerning
- with the purpose that → with the purpose of
Avoid pleonasms

Pleonasm are words or phrases that add no information.

- a case could be made
- a total of
- an interesting example is
- are used to
- as a matter of fact
- at some future time
- despite the fact that
- has the effect of
- human error
- in the case of
- in the form of
- in this experiment/study
- in the interests of
- in the process of
- interestingly
- I should add that
- it could be argued/said that
- it goes without saying
- it is agreed/clear/evident that
- it is believed
- it is important/interesting to note that
- it is worth noting that
- it may seem reasonable to suppose that
- it must be noted/emphasized that
- it should be mentioned that
- it was found that
- it would thus appear that
- needless to say
- nonetheless
- so far, we have seen that
- student error
- the fact of the matter is that
- the next thing to consider is
- this has implications for
- we wish to emphasize that
- will have
- with respect to
- would like to

The word “that” can often be removed from sentences.

I see that you have started the …. → I see you have started the ….
### Avoid vague and imprecise words

Scientific prose must be clear and concise. Vague and/or imprecise adjectives should be carefully reviewed to determine if a more specific phrase is appropriate. Some words sound knowledgeable, but are not specific. Often, they should be deleted and the sentence rewritten to be more precise.

<table>
<thead>
<tr>
<th>Vague Words</th>
<th>Precise Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>all, always</td>
<td>impact</td>
</tr>
<tr>
<td>approximately</td>
<td>infrastructure</td>
</tr>
<tr>
<td>broad-based</td>
<td>interesting</td>
</tr>
<tr>
<td>clearly</td>
<td>large, small</td>
</tr>
<tr>
<td>comparatively, relatively</td>
<td>like</td>
</tr>
<tr>
<td>conceptualize</td>
<td>literally</td>
</tr>
<tr>
<td>considerable</td>
<td>lots, little</td>
</tr>
<tr>
<td>currently</td>
<td>multifaceted</td>
</tr>
<tr>
<td>definitely</td>
<td>never</td>
</tr>
<tr>
<td>dynamics</td>
<td>obviously</td>
</tr>
<tr>
<td>every</td>
<td>parameters</td>
</tr>
<tr>
<td>exciting, incredible, wonderful</td>
<td>poor, good, great</td>
</tr>
<tr>
<td>exceptionally</td>
<td>rather, relatively</td>
</tr>
<tr>
<td>extremely</td>
<td>recently</td>
</tr>
<tr>
<td>fast, quick, slow</td>
<td>some</td>
</tr>
<tr>
<td>few, many, several, some</td>
<td>soon</td>
</tr>
<tr>
<td>formalize</td>
<td>quite</td>
</tr>
<tr>
<td>frequently, often</td>
<td>very</td>
</tr>
</tbody>
</table>

Consider the following examples.

The results were very significant because …  
A few samples showed signs of contamination.

(How much is “very”)
(How many? What signs?)

... redacted in preview ...
Additional resources …

... on English grammar
Definitions are adapted from http://www.dictionary.com

... on communicating science

Reconstructed paragraph: 3 1 5 4 2 (original on page 22)
Major earthquakes along a given fault line do not occur at random intervals because ...
... redacted in preview ...
You cannot become proficient at writing by only reading how to write. **Practice writing, practice reviewing, and practice editing your work and others’ work.**

You cannot become proficient at any activity — swimming, driving, communicating, research, … — by watching others. You must practice and, ideally, you must teach!

*The best ways to uncover problems in your prose is to read your work aloud. If you do not like the way it sounds, readers will not like the way it reads.*

Reading your work aloud will uncover problems with many aspects of your prose and help you achieve clarity, coherence, concision, and precision.
Chapter 2. Communicating scientific information

There are established methods of communicating scientific information. By following these standards, your document will have increased clarity, coherence, concision, and precision, all of which improve readability and reduce the chance of misinterpretation.

Be aware that language is dynamic and constantly evolving. As you continue your education and career, you will observe changes in the grammar and style used to communicate information. In science, this evolution also includes new terms to explain new concepts.

2.1 Formatting common information

Capitalization

Common nouns denote a class or group with similar features, and are not capitalized. Instruments and chemicals are common nouns.

- planet, country, city, apple, spectrometer, sodium chloride, …

Proper nouns denote a specific person, place, or thing; proper nouns are capitalized.

- Jupiter, Russia, London, Macintosh, Ocean Optics spectrometer, …
- out west vs. Western Canada

Some words can be both common and proper nouns, depending on the context.

- university (when referring to post-secondary education)
- University (when referring to a specific university)

... redacted in preview ...
Some words are proper nouns in some languages, but common nouns in others.

Monday (English) lundi (French)

Domain names are not case sensitive. However, the folder and file information in URLs is case sensitive.

www.nobelprize.org/nobel_prizes/  
not case sensitive  case sensitive

Email addresses are not case sensitive.

alfred.nobel@nobelprize.org  or  Alfred.Nobel@NobelPrize.org

Titles and headings should only have the first letter and proper nouns capitalized.*

Date and time

Write the date in order of either increasing or decreasing duration. The year may be omitted if it is previously stated or obvious. If there is potential ambiguity, write the month in letters.

13 November 2012  13/11/2012  (increasing duration)
2012 November 13  2012/11/13  (decreasing duration)

We are meeting next Tuesday, 13 November.

Consider the date 03/06/09: this could be 03 June 2009, 09 June 2003 following the increasing/decreasing convention. If this convention is not followed, the date could also be in March or September. Ensure the dates you write are unambiguous.

Report time in the 24-hour clock to avoid ambiguity. The 24-hour clock uses leading zeros so that each of hours, minutes, and seconds each have
Historical timelines need to distinguish events that occurred before or after the start of the Gregorian calendar. Two notations are common:

• Catholic notation (original notation)
  ◦ BC: *Before Christ*
  ◦ AD: *Anno Domini* (in the year of the Lord)*

  The Egyptian pyramids were built from 2670 BC to 660 BC.
  Mount Vesuvius erupted in AD 79 and destroyed much of Pompeii.

• secular notation
  ◦ CE: *Common Era*
  ◦ BCE: *Before Common Era*

  The Egyptian pyramids were built from 2670 BCE to 660 BCE.
  Mount Vesuvius erupted in 79 CE and destroyed much of Pompeii.

**Credentials and titles**

Titles may be abbreviated with or without periods. Both forms are correct, but whatever style you choose, use it consistently. It is not correct to have one period at the end of a multiword abbreviation.

```
Dr   or    Dr.
PhD. →  Ph.D. or PhD
MSc. →  M.Sc. or MSc
```

It is not appropriate to duplicate a title.

```
Dr. Jill Pye, Ph.D. → Dr. Jill Pye or Jill Pye, Ph.D.
```

**Phone numbers**

Formatting of phone numbers varies around the world.

```
123-456-7890   North American
```

... redacted in preview ...
Addresses

Addresses are written on a minimum of three lines.

- addressee (first line)
- <additional delivery information>
- street address (second-last line)
- community province/state postal/zip code (last line)

Note that there is no punctuation in the last line: the community and province/state abbreviation are separated by one space, and the province/state abbreviation and postal/zip code are separated by four spaces. Formatting your address this way allows the post office’s scanners to read the address; deviation from this standard can cause your mail to be misrouted.

Dr. Jordan Martin
Physics, University of Toronto
60 St. George Street
Toronto ON M5S 1A7

To write an address in sentence form, separate each line with a comma.

Dr. Jordan Martin, Physics, University of Toronto, 60 St. George Street,
Toronto ON M5S 1A7, Canada

If shipping to another country, include the country on an additional line.

Mr. Sidney Gagnon
Science, Lynn High School
50 Goodridge Street
Lynn MA 01902
USA

Dr. Wolfgang Müller
Max Planck Institute for Physics

... redacted in preview ...
2.2 Formatting scientific information

The International Organization for Standards (ISO) publishes guidelines for communicating scientific information. ISO develops standards to promote good practices, open communication, and international trade. Each scientific discipline publishes a guide that focuses on the ISO standards common in its discipline. Communicating Science presents commonly used ISO standards. For details on specific disciplines, consult the following resources.

**Biology**: Quantities, Symbols, Units, and Abbreviations in the Life Sciences (IUMBM, IUBS)

**Chemistry**: Quantities, Units, and Symbols in Physical Chemistry (IUPAC)

**Physics**: Commission on Symbols, Units, Nomenclature, Atomic Masses and Fundamental Constants (IUPAP)

**Engineering**: <each engineering division — chemical, civil, electrical, mechanical — publishes their own style guide>

### Mathematical equations

The formatting of the factors in mathematical equations provides information on the nature of the factor.*

- italicized serif font: $a, b, c$
  - *constants*: $\pi (= 3.14159...)$, $i (= \sqrt{-1})$, $e$ (electron charge)
  - *variables*: $x, y, z, P, V, m, T$

- upright serif font: a, b, c
  - *numbers*: 1, 2, 3, ...
  - *functions*: $\cos, \ln$, e (as exponential function, $e^x$), $\Delta$

* ... redacted in preview ...
Communicating scientific information

Examples

\[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]
\[ A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \]
\[ c^2 = a^2 + b^2 - 2ab \cos(C) \]
\[ d = d_0 + vt + \frac{1}{2}at^2 \]
\[ F = ma \]
\[ k(T) = A e^{\frac{E_a}{RT}} \]
\[ \Delta_G^0 = -RT \ln(K) \]
\[ PV = nRT \]
\[ 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) = 2 \text{H}_2\text{O}(l) \]

Numbers

When reporting quantities, use words for numbers up to and including ten, and numerals for numbers above ten.

We collected four samples. We collected 27 samples.

If a data set contains numbers below and above ten, use numerals for all numbers.

Samples 3, 7, and 12 showed signs of contamination.

When reporting data, use numerals. Numbers less than one require a leading zero and a decimal point. In all cases, the units should be treated as separate words and separated from the numeric value.

1.75 g 122.86 $

1.10 V 0.84 m/s

Exception: there is no space when reporting degrees, minutes, and seconds in angles and position

41° 43' 55" N, 49° 56' 45" W

Fractions less than one are written as either words or numerals. Fractions ...

... redacted in preview ...
Uncertainty

The number of digits in a reported number indicates the precision to which that value is known. The values 4, 4.0, and 4.00 have different precision. In introductory courses, the uncertainty is often assumed to be \pm 1 in the last reported digit.

\[
4 \pm 1 \\
4.0 \pm 0.1 \\
4.00 \pm 0.01
\]

In advanced courses and in publications, the uncertainty in the number is explicitly reported. Uncertainty is estimated in measurements and carried through calculations using propagation of uncertainty (see Section 2.7).

\[
4.00 \pm 0.06
\]

For large and small numbers, scientific notation simplifies the number and correctly indicates the uncertainty of the value.

\[
65\,000\,000 \text{ years} \rightarrow 6.5 \cdot 10^7 \text{ years} \rightarrow (6.5 \pm 0.2) \cdot 10^7 \text{ years} \\
0.00784 \text{ mol/L} \rightarrow 7.84 \cdot 10^{-3} \text{ mol/L} \rightarrow (7.84 \pm 0.05) \cdot 10^{-3} \text{ mol/L}
\]

Report values as decimals unless the fraction is absolute, then it is permissible to use fractions.

\[
\frac{3}{20} \text{ samples were contaminated.} \\
15\% \text{ of the samples were contaminated.} \\
\text{Fifteen percent of the samples were contaminated.}
\]

Units

If someone were to tell you that 5 = 11, you would question their intelligence. However, it is true that 5 kg = 11 lb. Units are necessary for understanding. All measurements must include both a
Units are not pluralized unless written in full.

1.0 kg, 7.5 kg  
1.0 kilogram, 7.5 kilograms

Units are symbols, not abbreviations. There is no period after any metric unit.*

Numerals and units follow the rules of mathematics.

1.50 cm × 2.00 cm  
not 1.50 × 2.00 cm

25 °C to 28 °C  
or (25 to 28) °C  
not 25 to 28 °C

12.62 g ± 0.04 g  
or (12.62 ± 0.04) g  
not 12.62 ± 0.04 g

To present complex units, use brackets or full mathematical notation.

\[ \frac{J}{\text{mol K}} \]  
or \[ J \text{ mol}^{-1} \text{ K}^{-1} \]  
or \[ \frac{J}{\text{mol K}} \]  
not \[ J/\text{mol K} \]

**Spacing within mathematical expressions**

There is a space between every symbol in a mathematical formula: scalars, variables, functions, units, and operations (+, −, ×, ÷, =, …). In other words, punctuate each symbol as if it were a word.

\[ y = mx + b \]  
\[ x = 14\% \]  
\[ m = 14.65 \text{ g NaCl} \]

\[ b < 3 \]  
\[ T = (310 \pm 2) \text{ K} \]  
\[ d = 0.274 \text{ m} \]

**Exceptions:**

\[ \frac{13}{20} \]  
\[ v = \frac{d}{T} \text{ kJ/mol} \]  
no space around the solidus (division symbol)

\[ \frac{1}{2} m v^2 \]  
\[ ^{12}C \text{ e}^{-x} \]  
no space when the factor is super or subscripted

\[ \text{H}_2(g) \]  
no space between a label and the quantity it applies to

\[ F = ma \]  
\[ 5.8 \cdot 10^{-4} \]  
no space around the dot used for multiplication

\[ T = (310 \pm 2) \text{ K} \]  
no space between the bracket and values inside the bracket

\[ t = 14.3 \text{ °C} \]  
no space in the “degrees celsius” units†

\[ \theta = \circ ' " \]  
no space when reporting degrees, minutes, and seconds

... redacted in preview ...
Plural symbols and numerals

For symbols and abbreviations, add ( ’s ).

\[ \Delta H^\circ \text{'s calculated for the system} \quad \text{CFC’s} \]

For numerals, add ( s ).

- 1990s means the range from 1990 – 1999.
- 1990’s means something belonging to 1990.
- ’90s is an abbreviation of 1990s.

Mathematical expressions in sentences

Two practices are common when including mathematical expressions in sentences: using the unit symbols or writing them out in full. If the units contains more than two terms, the symbols must be used. When the units are written in full, a hyphen may be used to join the numeral and the units. Whichever practice you follow, be consistent throughout your work.

- \( 5.5 \text{ kg} \) or \( 5.5 \text{ kilograms} \) or \( 5.5\text{-kilograms} \)
- a 25 mL aliquot or a 25-milliliter aliquot not a 25-mL aliquot
- 125 V/cm or 125 V cm\(^{-1}\) or 125 volts per centimeter
- 8.57 cm\(^3\) or 8.57 cubic centimeters
- 1.26 mol/(L s) or 1.26 mol L\(^{-1}\) s\(^{-1}\) not 1.26 moles per liter per second

Variables and scientific terms can either be condensed or written in full:

- The standard reaction enthalpy is the heat energy exchanged …
- The heat energy exchanged, \( \Delta H^\circ \), …
- The Fe\(^{3+}\) concentration is \( 2.83\cdot10^{-2} \text{ mol/L} \).
- The iron(III) concentration is \( 2.83\cdot10^{-5} \text{ mol/L} \).

When used in sentences, punctuate all mathematical components

... redacted in preview ...
Mass versus weight

The terms *mass* and *weight* have different meanings in science than in society.

- **Mass** is measured in kilograms; the mass of an object is constant.
- **Weight** is a force and measured in newtons.

Weight and mass are related through the mathematical relationship

\[ \text{weight} = \text{mass} \times \text{acceleration} \]

Consider a mass of 75.0 kg

- standing at sea level: \( g = 9.81 \, \text{m/s}^2; \, w = 7360 \, \text{N} \)
- on the top of Mount Everest: \( g = 9.76 \, \text{m/s}^2; \, w = 7320 \, \text{N} \)
- in a car accelerating horizontally at 5.00 \(\text{m/s}^2\): the net acceleration is 11.01 \(\text{m/s}^2\) and the weight is 8250 N
- in orbit around the earth: \( g = 0.0 \, \text{m/s}^2; \, w = 0 \, \text{N} \)

Even in scientific prose, *weight* is sometimes used incorrectly.

<table>
<thead>
<tr>
<th>Incorrect Use</th>
<th>Correct Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>The <em>weight</em> of Sample 7 is 22.65 g.</td>
<td>The <em>mass</em> of Sample 7 is 22.65 g.</td>
</tr>
<tr>
<td>Weigh the samples before and after heating.</td>
<td>Measure the <em>mass</em> of the samples before and after heating.</td>
</tr>
</tbody>
</table>

Experimental labels

Experiments are conducted under varying conditions. Labels such as *condition A, condition B, …* contain no information about the experimental conditions and require the reader return to the experimental section to recall the experimental conditions. A better option is to assign meaningful labels to the experiments so that the reader is aware of the

... redacted in preview ...
2.3 Copyright and plagiarism

Copyright is a legal right granted to the creator of a work, giving the creator exclusive rights to publish, produce, sell, and distribute the work. Works can be written (literary, academic), musical, dramatic (plays, concerts, movies, presentations), and artistic (paintings, photos, sculptures). Copyright law also allows the creator to transfer their copyright to others.

In the context of Communicating Science, the documents you prepare are academic works, and the presentations you give are dramatic works.

In most countries, copyright exists the instant a work is produced. There is no requirement for any copyright symbol or statement, but it is common practice to include the copyright symbol, the creator, and the year the work was created: © Roy Jensen, 2014. The author of the work holds the copyright unless there is an agreement to the contrary or an employment relationship that transfers copyright to their employer.

The duration of copyright depends on the country. It could be as long as

- 95 years from the date created if the copyright holder is a company
- 95 years from the date of death if the copyright holder is a person

After the copyright has expired, the work becomes public domain, meaning that anyone can use the work for any purpose. However, you must still cite public domain works unless the information is common knowledge.

In general, you must ask permission from the copyright owner to use their work. However, there are certain situations when permission is not required. The fair use and fair dealing provisions (terminology varies by... redacted in preview...
An important consideration as to whether use qualifies as fair use/dealing is the amount of work copied and the reason for using it.

Copying an entire work completely for research, criticism, or parodying may be acceptable as fair use/dealing. For example, copying an entire poem for use in a book analyzing poetry may be acceptable. In addition, numerous comedy movies have scenes that parody other movies. Conversely, copying a small portion of a book and using it in another book is likely not fair use/dealing. For example, copying material out of a textbook so students do not have to purchase the textbook violates copyright laws.

The research and personal study and news reporting provisions of fair use/dealing allow you to quote someone else in your work without their permission. However, you must still cite their work!

**Plagiarism**

*Plagiarism* is to knowingly pass off the original and distinctive ideas or work of another author as your own without crediting the author and when the context of such use expects the work to be cited.

Consider the following text:

A hypothesis is a proposed and testable explanation of a phenomenon. A good hypothesis explains the phenomenon and predicts the outcome of future research. If the predictions are incorrect, the hypothesis is rejected. If the predictions are correct, the hypothesis gains strength and credibility. The predict–test–update hypothesis cycle continues to refine the hypothesis to more accurately explain the phenomenon and to establish the applicable range of the hypothesis. Once understanding is achieved, the results are published. Publishing adds this information to the body of scientific knowledge for other scientists to evaluate, support, criticize, and build upon. If the hypothesis gains acceptance in the scientific community, it becomes a
• paraphrasing the idea without acknowledging its source

A hypothesis is a proposed explanation of an observed phenomenon that predicts the outcome of future research. A hypothesis that correctly explains the phenomenon and correctly predicts the outcome of future research is assumed to be correct and is published. If the hypothesis gains acceptance in the scientific community, it becomes a theory.

Context plays an important role in determining whether information should be cited. The established practice for persons preparing scholarly documents is to cite information taken from other sources. However, that same rigorous requirement does not apply in all contexts:

• Administrators writing policies review existing policies from other institutions and often copy sections verbatim or with minor modification, but rarely are these sources cited.

• In legal cases, judges prepare their decision using arguments written by attorneys, but without citing the attorney.

• Ghostwriting is common in publishing companies. Ghostwriters write novels that are published under the name of a popular author, increasing sales. Additionally, celebrities hire ghostwriters to write their memoirs and autobiographies.

• Academic instructors routinely create assignments and exams using questions taken from textbooks. The sources are rarely cited.

• Textbooks contain numerous real-world examples to illustrate the importance and applicability of the material in the text and questions. Only rarely are sources cited.

In these and many other contexts, the citation expectations differ from the rigorous expectations when preparing academic scholarly documents.

Common knowledge

... redacted in preview ...
When does a concept go from requiring citation to becoming common knowledge? It depends on the person, their knowledge, the concept, and the work they are preparing. For example, the common knowledge of a scientist practicing in a discipline is different from a student learning the discipline. The common knowledge of a mathematician differs from that of a biologist. As a rule, if you look up information (other than scientific constants) and rely on that document to prepare your own document, that source must be cited. If in doubt, it is best to cite the source.

Copyright laws and the concept of plagiarism are changing as the world adapts to new technology and the information age. You should use the guidelines of your instructor, employer, or publisher when preparing scholarly works.

**Non-copyrightable information**

First, certain information is not copyrightable:

- ideas  
- discoveries  
- facts  
- processes

In law, you may reproduce this information without citation. However, from an academic perspective, you should cite the source to give credit to the creator, to add credibility to the information you present, and to avoid allegations of plagiarism.

For example, consider a scholarly article that contains a procedure (a process) for setting up and conducting an experiment. Others can reproduce the procedure in their work, either verbatim, paraphrased, or with improvements. In law, the procedure does not require citation. In academia, the procedure requires citation. Conversely, you do not need to cite the source when looking up physical constants (facts).
Public copyright licenses

The advent of the internet and the plethora of documents available online has revealed a limitation of existing copyright laws: it may be difficult to identify and obtain permission from the copyright holder.

To address this limitation using the existing laws, public copyright licenses were proposed that allow the copyright holder to grant others permission to use the work with certain conditions. One type of public copyright license is the Creative Commons license. The Creative Commons organization proposed four terms that can be selected by the copyright holder and forms the foundation of the Creative Commons, ©, license. Table 2.1 summarizes these terms. All licenses require the *attribution* term plus any combination of the other terms. With the exception of work licensed with the *no derivative* condition, you may modify and adapt the original work into your own (called a *derivative work* in law).

Table 2.1 Possible terms that a creator could require of licensees using a Creative Commons license.

<table>
<thead>
<tr>
<th>Licence terms</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>attribution (BY)</td>
<td>Licensees must give appropriate credit to the creator, provide a link to the CC license, and indicate if changes were made. (required)</td>
</tr>
<tr>
<td>share alike (SA)</td>
<td>Licensees must distribute the derivative work under the same licence as the original work. (optional)</td>
</tr>
<tr>
<td>non-commercial (NC)</td>
<td>Licensees may not use the creator’s work for commercial purposes. (optional)</td>
</tr>
<tr>
<td></td>
<td>Licensees may only use the creator’s work verbatim (optional)</td>
</tr>
</tbody>
</table>

... redacted in preview ...
2.4 Citations

A citation provides a reader with sufficient information to locate a work used by the author. This ensures that people receive credit for their knowledge and allows the reader to obtain more information about topics they are interested in. By knowing the source, a reader can also assess the credibility and potential biases of the information. For example, Greenpeace and OPEC (a consortium of petroleum producers) may have significantly different perspectives on climate change and pollution.

Citation styles

Numerous organizations have developed style guides. Some common style guides include:

- Modern Language Association (MLA) style, commonly used in literature, arts, and humanities.
- Chicago style, commonly used in non-scholarly books, magazines, and newspapers. (A variant of Chicago is the Turabian style.)
- American Medical Association (AMA) style, commonly used in medical and health disciplines.

Several scientific organizations have developed style guides as well.

- The Council of Science Editors (CSE) style
- American Chemical Society (ACS) style
- American Institute of Physics (AIP) style
- Institute of Electrical and Electronics Engineers (IEEE) style
- American Psychological Association (APA) style

... redacted in preview ...
No one style is better than any other. Consequently, there is little interest in switching to a common style. An instructor, employer, or publisher will select a style so that information is communicated in a consistent manner. As a writer, you must follow their style requirements when submitting documents to them.

Style guides address all aspects of document formatting, from text to tables to citations. However, there is significant commonality and flexibility among formatting guidelines, so the focus of instructors is often on formatting citations.

The citation format in *Communicating Science* is based on the Council of Science Editors (CSE) style manual. The text box on page 80 and the Variations section on page 86 provide information on and rationalize alternate citation styles.

### Citation formats

Citations are commonly ordered *alphabetically* or *numerically*, which introduces two common citation formats.

The *alphabetical* (*name-year; Harvard*) format uses parenthetical references in the text body and orders the references alphabetically by author at the end of the document, in a section commonly called *Bibliography* or *Works cited*.

<table>
<thead>
<tr>
<th>Format</th>
<th>Text (in text)</th>
<th>Bibliography (in text)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Author Year) or (Author Year, page)</td>
<td>&lt;full citation to original work&gt;</td>
<td></td>
</tr>
</tbody>
</table>

The *numerical* (*citation-sequence; Vancouver*) format uses numbers in the text body and orders the references numerically at the end of the document in a section commonly called *References*.

#...

... redacted in preview ...
Details on the alphabetical format

This format is commonly used in biology and environmental science.

There are several nuances of the in-text component of citations:

• If there is one author, list the author’s last name and the year of publication.
  
  (Jones 2004)

• If there are two to three authors, list them together.
  
  (Jones, Nguyen, and Robinson 2008)

• If there are more than three authors, list only the first author and add ‘et al.’ to indicate the existence of additional authors.
  
  (Martinez et al. 2009)

• If required to differentiate between publications, more than one author can be listed.
  
  (Martinez, Carter, et al. 2011)
  
  (Martinez, MacDonald, et al. 2011)

• If multiple authors have the same last name and publish in the same year, include sufficient initials to differentiate the authors.
  
  (Smith L 2007)
  
  (Smith T 2007)

• If an author has published more than once in a given year, use a, b, c, … after the year to sequence the publications chronologically.
  
  (Torres 2006a)
  
  (Torres 2006b)

• If there are multiple citations, list them chronologically and separated by semicolons.

... redacted in preview ...
Details on the numerical format

This format is commonly used in chemistry, physics, and mathematics.

In the text, the reference number is either superscripted* or enclosed in brackets: (#) or [#]. There are several nuances of the in-text component of citations:

• Place the number close to the information being referenced or to the author of the information.
  
  Westwood¹ explored the effect of parasitic weeds on native …
  Parasitic weeds decreased the growth rate and lifespan of native vegetation.¹

• Number citations in order of first occurrence.

• If there are multiple citations to the same information, number them chronologically.

• Separate multiple in-text citations using commas, but without spaces.

• Join more than two consecutive citations with an en-dash.
  
  The mass spectrometer is a powerful instrument that has applications in chemical analysis,¹–⁴ isotopic analysis,⁵,⁶ dissociation dynamics,²,⁷ and proteomics.³,⁵,¹⁰–¹²

  … dynamical status of galaxy groups and clusters [3,4]. The most active supercluster nuclei contain more early-type galaxies [5–8].

Full citations

The differences between citation formats are cosmetic. There is no universally accepted citation format and all citations convey similar information. However, you must use the citation format dictated by the instructor, employer, or publisher to whom you are submitting your work.

... redacted in preview ...
organization. Commas are not used to separate the last name and initials.

- Semicolons separate related items within a component, such as the publisher and publication year.
- Colons separate the title from the subordinate title and the publisher and from the place of publication.

Citations must contain sufficient information to locate the work, but often contain more information than required. This redundancy allows a resource to be found even if there is an error in the citation. In addition, not all the information may be known for a citation, so that information may be omitted without losing the ability to locate the work.

Numerous factors affect the citation format adopted by an organization. For journal publishers, space is a big factor, especially when every article cites tens of references. In developing a citation style, publishers endeavor to reduce the space required for citations by omitting information. The following three citations all provide sufficient information to find the reference.


While the first two have some redundancy, the last does not. An error in the last citation would make it impossible to find the article.

**Book with author(s)**

... redacted in preview ...
Electronic book

Author(s). Year.\textalpha Title [internet]. Edition. Place of publication: Publisher; Year\textsuperscript{numeric} [cited \textless date\textgreater]. Available from: <URL>

(The author is an organization in this example.)


Book chapter, for books where each chapter has a different author

Author(s). Year.\textalpha Chapter title, in: Book title. Edition. Chapter \textless #\textgreater. Editor(s), editor(s). Place of publication: Publisher; Year\textsuperscript{numeric}


\textbf{numeric}: #. Cook HJ. Physicians and natural history, in: Cultures of natural history. Chapter 6. Jardine N, Spary EC, Secord JA, editors. New ... redacted in preview ...
82 Communicating scientific information

**Online journal article**


**Conference proceedings article**

Author(s). Date. Article title. In: Editor(s). Proceedings title; Place of conference. Place of publication: Publisher; Date. Page range.


**numeric:** #. Lee DJ, Bates D, Dromey C, Xu X, Antani S. An imaging system correlating lip shapes with tongue contact patterns for speech pathology research. In: Krol M, Mitra S, Lee DJ, editors. Proceedings of the 16th IEEE Symposium on Computer-Based...

... redacted in preview ...
Technical report
Author(s). Year. Title. Report number. Place of publication: Publisher; Year.


Course material
Author(s). Year. Course. Title. Place of publication: Publisher; Year.


Magazine
Author(s). Date. Article title. Magazine title. Date; Volume(Issue):Page range.


... redacted in preview ...
**Encyclopedia**


**Page or document from a website**


**Presentation**

A presentation may only be cited if you have a copy of the presentation to confirm what was presented.

... redacted in preview ...
2.4 Citations

Author. Date. Personal communication. Affiliation. Date.

**alpha:** Tarver, CM. 14 August 2004. Personal communication. Lawrence Livermore National Laboratory.

**numeric:** #. Tarver, CM. Personal communication. Lawrence Livermore National Laboratory. 14 August 2004.

**Citing multimedia**

*Multimedia* is everything other than text in your work: tables, figures, images, graphs, audio, and video.

You must cite multimedia created by another author, but the citation is usually at the location of the multimedia. For tables, figures, images, and graphs, the citation is commonly in the caption or in a footnote on the same page. For audio and video, the citation is commonly in a footnote on the same slide as the audio or video.

If you are using multimedia under a fair use/dealing exception, add the following component to the normal citation.

- If the multimedia is identical to the original, write the citation as,
  
  Source: <full citation>

- If the multimedia is modified from the original to better suit your work, write the citation as,
  
  Adapted from <full citation>


... redacted in preview ...
If you have obtained permission to use another creator’s multimedia, the copyright owner has the right to dictate the location and format of the citation. (For example, see the images on page 8, 126, 265, and 280.) If they do not specify a citation format, cite the multimedia as above. Add the following phrase to the end of the citation:

Used with permission.

**Additional information added to citations**

**Online resources**

References to online resources add three components to the citation:

- the phrase “[internet]” after the title
- the date cited
- the URL at the end of the citation. (There is no period after the URL.)

Additionally, keep a copy of the resource so that you can easily refer to it or provide it to others if required. If the resource is a website, print the relevant page(s) as a PDF.

**Articles found in a database**

Electronic databases index published work. If you find a reference using a database, acknowledge the database in the citation by adding the following phrase to the end of the citation:

Retrieved on <date> from <database name>.

**Digital object identifiers**

Scientific journals may assign a digital object identifier (DOI) to online articles. The DOI is a short unique identifier that links to the article
Other formats have different internal punctuation and apply italic and bold formatting to title, year, volume, and issue. Two examples are

**American Institute for Physics (AIP) style**


**American Chemical Society (ACS) style**


**Using material without permission**

The same text and multimedia are often found on multiple websites. It is sometimes challenging to determine the source of the material and challenging to obtain permission from the copyright holder to use their material. If the author cannot be determined, state in a footnote or in the caption that the information is available from multiple sources online and there is no clear indication of whom the original author is.

[Page 367] An internet search for “science rubric” returns a plethora of rubrics. Many of them are duplicates of each other and there is no indication of the original author. The rubrics in this section were adapted from those found online, but it is not practically possible to identify and credit the original authors.

If you do identify the copyright holder, but they do not respond, you should assume that they do not grant permission and you should not use their material.

... redacted in preview ...
2.5 Presenting scientific data: tables

Tables are a natural way to record and present data in a convenient and logical format. Trends are more-readily observable when tabulated. Electronic tables can also be manipulated: columns added and deleted, calculations done, and the table formatted for publication.

Both word processors and spreadsheets are capable of making publication-quality tables. Examples of quality tables are found in Communicating Science, textbooks, and in published scholarly articles.

Scientific tables have:
- clear and concise headings
- numerical data formatted to clearly and accurately present the data, with appropriate significant digits
- units transferred to the headings
- a minimum number of horizontal and vertical dividing lines

Tables are numbered sequentially and should be referred to in the text. If possible, integrate the reference into the sentence.

The results are tabulated in Table #.
The data in Table # summarizes …

Tables are captioned at the top. The caption concisely explains the data in the table and provides brief details on any information in the table that may be difficult to understand. The caption should be a maximum of three sentences. A table and caption should contain sufficient information to be understandable without the reader having to reference the text.

<table>
<thead>
<tr>
<th>A recurring example used in sections 2.5 and 2.6 is an iron analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>... redacted in preview ...</td>
</tr>
</tbody>
</table>
Table 2.2 presents the raw data collected from the calibration standards and an unknown sample.

**Table 2.2** Absorbance at 450 nm of iron(III) standards and unknown. Iron(III) exists as iron(III) thiocyanate.

<table>
<thead>
<tr>
<th>label</th>
<th>Fe$^{3+}$/ (mol/L)</th>
<th>$A_{450 \text{ nm}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>standards</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std. 1</td>
<td>$6.73 \cdot 10^{-5}$</td>
<td>0.593</td>
</tr>
<tr>
<td>std. 2</td>
<td>$5.07 \cdot 10^{-5}$</td>
<td>0.475</td>
</tr>
<tr>
<td>std. 3</td>
<td>$3.39 \cdot 10^{-5}$</td>
<td>0.336</td>
</tr>
<tr>
<td>std. 4</td>
<td>$1.68 \cdot 10^{-5}$</td>
<td>0.199</td>
</tr>
<tr>
<td><strong>unknown</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>unk. A</td>
<td>$3.25 \cdot 10^{-5}$</td>
<td>0.325</td>
</tr>
<tr>
<td></td>
<td>$3.35 \cdot 10^{-5}$</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>$3.28 \cdot 10^{-5}$</td>
<td>0.328</td>
</tr>
</tbody>
</table>

When tabulating data, transfer the units to the heading following the rules of mathematics. In Table 2.2, the iron(III) concentration has units of mol/L. Absorbance is dimensionless.

\[
\text{Fe}^{3+} = 6.73 \cdot 10^{-5} \text{ mol} \quad \frac{\text{mol}}{L} \quad \Rightarrow \quad \frac{\text{Fe}^{3+}}{\text{mol}} = 6.73 \cdot 10^{-5}
\]

2.1

This can also be written on a single line with brackets used to remove the ambiguity in the units.

\[
\text{Fe}^{3+} / (\text{mol/L}) = 6.73 \cdot 10^{-5}
\]

2.2

... redacted in preview ...
The replicate measurements of the unknown provide a mechanism for estimating the accuracy of the data. Two common calculations are the average and standard deviation. (Section 2.7 provides more information on the statistical analysis of data.)

\[
\text{Unknown A} \\
\begin{align*}
\text{average} & : 3.30 \cdot 10^{-5} \text{ mol/L} \\
\text{standard deviation} & : 5 \cdot 10^{-7} \text{ mol/L}
\end{align*}
\]

\[
(3.30 \pm 0.05) \cdot 10^{-5} \text{ mol/L}
\]

Table 2.3 presents the calibration and unknown data that would be in the final report. The raw data (Table 2.2) may be in an appendix to the report.

**Table 2.3** Absorbance at 450 nm of iron(III) standards and unknown. Iron(III) exists as iron(III) thiocyanate. The uncertainty is the standard deviation.

<table>
<thead>
<tr>
<th>label</th>
<th>Fe(^{3+})/mol/L</th>
<th>(A_{450\text{ nm}})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>standards</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>std. 1</td>
<td>6.73 \cdot 10^{-5}</td>
<td>0.593</td>
</tr>
<tr>
<td>std. 2</td>
<td>5.07 \cdot 10^{-5}</td>
<td>0.475</td>
</tr>
<tr>
<td>std. 3</td>
<td>3.39 \cdot 10^{-5}</td>
<td>0.336</td>
</tr>
<tr>
<td>std. 4</td>
<td>1.68 \cdot 10^{-5}</td>
<td>0.199</td>
</tr>
<tr>
<td><strong>unknown</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average:</td>
<td>((3.30 \pm 0.05) \cdot 10^{-5})</td>
<td></td>
</tr>
</tbody>
</table>

... redacted in preview ...

2.6 Presenting scientific data: figures, images, and graphs

Presenting information as a figure, image, or graph provides an overview of the information and allows a reader to visualize trends in data. A glance at a well-prepared figure, image, or graph may interest a reader to read the entire work.

*figure*: (schematic, diagram, line drawing) a pictorial representation of an object or process

*image*: (photograph, realistic drawing) a visual reproduction

*graph*: (chart) a representation of the quantitative relationship between two or more quantities, or a mathematical relationship

While there is a formal difference between figures, images, and graphs, many people commonly use *figure* to refer to all three, and *figure* is used in captions of figures, images, and graphs.

Figures provide a visual presentation of complex information, which aids in understanding. Figures are commonly used to present information about the experimental method, experimental setup, and the data and analysis. Figures should only contain details relevant to the project. A challenge in preparing figures is determining what to include and how to prepare the figure to best convey the desired information. In general, simpler figures are better than complex figures.

If you are using a figure produced by someone else, ensure that you have permission to use it or that you are using it under one of the fair use/dealing provisions (see Section 2.3).

Figures should be between half and a full page in size. When making figures and graphs, use a vector format so that it scales to any size. (Vector formats also have a smaller file size.) Images, such as ... redacted in preview ...
Color in figures, images, and graphs

Color is readily available in word processors, spreadsheets, and graphics software. Used correctly, color highlights information and makes interpretation easier. However, the cost is three to five times higher for both students and publishers. Unlike high school and first-year textbooks, most advanced textbooks and scholarly articles are printed in grayscale. Alternatives to color include using different symbols, line styles, and shading to differentiate data in grayscale figures (see page 100).

Another problem with figures is that reproduction (photocopying) is not perfect. Subtle shades and colors are lost when reproduced. This is especially true for images. When using color, ensure the entire figure is interpretable when photocopied or printed in grayscale.

Figures

Common figures include flow charts, instrument schematics, and line drawings. They are created to illustrate a process, and can be created with varying amounts of detail, depending on the audience.
Figure 2.2  A line drawing by John Gould showing the variation in the finch beaks on the Galapagos islands, discovered during Charles Darwin’s expedition.
Figure 2.4  Realistic representation of an Ocean Optics QE 6500 diode array spectrometer showing the components and light path. Compared with Figure 2.3, ①, ② and ③ are the detector entrance and slits, ④ and ⑤ are mirrors, ⑥ is the diffraction grating, ⑦ is the optical filter, and ⑧ is the diode array detector. The source and sample are external to the spectrometer and not shown. (Used with permission.)
Figures 2.3, 2.4, and 2.5 present information on the same experimental apparatus, but the information conveyed in each figure is different. Figure 2.3 presents a simplified schematic. Figures 2.4 focuses on the detector. Figure 2.5 presents the actual experimental setup. The figure required in a document depends on the information to be conveyed.

**Graphs**

Graphs allow the reader to visualize data and identify trends in the data. You can find examples of quality graphs in *Communicating Science*, in textbooks, and in published scholarly articles.

Figure 2.6 presents the Cartesian axis with possible graphs that you may be expected to make. Observe that graphs do not need to include \( \{0, 0\} \).
Figure 2.7 A graph with a logarithmic y axis, illustrating how the axis is numbered.

Features of a quality scientific graph

Plotting data:
• The $x$-axis is the controlled (independent, manipulated) variable; the $y$-axis is the dependent (responding) variable.
• The axes ranges should be set so that the plotted data occupies most of the graph area while still having reasonable ranges.
• Adjust the axes scales so there are between four and six numbers on the axes, and the tick marks are a reasonable integer or fractional... redacted in preview ...
permissible to use a line to join the data points and not display the individual data points.

- Best-fit lines (trendlines), if used, should be added by the software.
- Include a legend if you have more than one data set on a graph.
- Do not plot gridlines unless you are extracting data directly from the graph.

Labeling the graph:

- The axes labels must identify what is being plotted and the units.
- Use either a title or caption — not both.
- The title must provide additional information about the graph: the system studied, the object of analysis, etc. *Do not repeat the axes labels!*

- Adjust the fonts, colors, and line thicknesses so they are legible in the final work.

![Graph example](image-url)
The wavelength plotted on the $x$-axis has units of nanometers. These units are transferred to the axis label using the mathematical procedure presented previously.

\[
\text{wavelength} = 500 \text{ nm} \implies \frac{\text{wavelength}}{\text{nm}} = 500
\]

Table 2.2 (page 89) contains the concentration and absorbance data of the iron(III) thiocyanate standards and unknown. Plotting the standards produces the calibration curve plotted in Figure 2.9.

... redacted in preview ...
\[
y = 7844.9 \times + 0.0701 \quad \Rightarrow \quad A_{450\text{nm}} = 7844.9 \frac{\text{L}}{\text{mol}} [\text{Fe}^{3+}] + 0.0701
\]

\[
A_{450\text{nm}} + 0.0701 = 7844.9 \frac{\text{L}}{\text{mol}} [\text{Fe}^{3+}]
\]

\[
[\text{Fe}^{3+}] = \frac{A_{450\text{nm}} + 0.0701}{7844.9 \frac{\text{L}}{\text{mol}}}
\]

The unknown concentration is determined using the measured absorbance.

\[
[\text{Fe}^{3+}]_{\text{ukn}} = \frac{0.329 + 0.0701}{7844.9 \frac{\text{L}}{\text{mol}}} = \frac{3.30 \cdot 10^{-5} \text{ mol}}{\text{L}}
\]

Significant figures in the original measurements dictate the significant figures in the unknown iron(III) concentration.

**Hand-drawn graphs**

Drawing graphs by hand is the best way to learn how to create a quality graph that conveys the most information possible. Once mastered by hand, it is much easier to create a quality graph on a computer.

Figures 2.8 and 2.9 are computer-drawn. Figure 2.10 is a hand-drawn version of Figure 2.9.

When preparing graphs by hand,

- Use 1 mm grid graph paper to assist in pinpointing the data points and slope.

... redacted in preview ...
**Plotting multiple data sets**

It is common to plot multiple data sets on the same graph to show the similarities and differences between the data sets. Take care when ... **redacted in preview** ...
To assist readers, you should use two methods to distinguish the data sets. Possible methods include

- colored lines, selected so that their grayscale colors are different
- labeling each line with a number, letter, label, or obvious identifier
- if there are few data points, use different data-point markers that are the same color as the line: ■, ●, ♦, □, ○, …
- if there are many data points, use different lines styles

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>solid</strong></td>
<td>____________________</td>
</tr>
<tr>
<td><strong>dash</strong></td>
<td>----------------------</td>
</tr>
<tr>
<td><strong>long dash</strong></td>
<td>---------------------</td>
</tr>
<tr>
<td><strong>chain</strong></td>
<td>-------------------</td>
</tr>
</tbody>
</table>

**Figure 2.12** Selected line styles. Unless one line is more important, use the same line width for all lines. Section B.2 (page 342) provides information on creating publication-quality graphs.

To identify the data set, include a legend either on the graph or in the caption.
Graphing non-linear data

Graph non-linear data like linear data. While linear regression is not possible, it is possible to fit a mathematical equation to the data and plot that fit. (See the section on using Excel® Solver in Appendix B.)

![Diagram](image)

**CO$_2$(g) → CO$_2$(aq)**

The data fit to:

\[ P_{CO_2} = P_{CO_2}^0 e^{-kt} \]

gives:  

\[ k = 0.0726 \text{ min}^{-1} \]

**Figure 2.14** Dissolution of carbon dioxide in water occurs as a first-order reaction with a rate constant of 0.0726 min$^{-1}$.  

... redacted in preview ...
Scatter plots

The data presented in Figures 2.9, 2.10, 2.14 show little scatter, so only a few data points are necessary to determine the relationship between the data. However, scatter is common in some experiments, and more data is required to determine the relationship. When preparing scatter plots, choose a dot size that makes each data point visible.

Figure 2.15  Height:age relationship for men and women aged 2 to 80.


... redacted in preview ...
Bar graphs
In some cases, numerical data can be grouped into categories that are not quantitative (i.e., not numerical). To represent this data graphically, a bar graph plots the data in each category as vertical or horizontal bars, evenly spaced along the axis. Numerical data with a regular interval can also be displayed in a bar graph, but only if there are fewer than ten data points.

Figure 2.16  The surface area of the continents.

Figures 2.17 and 2.18 present two ways multiple data from the same category may be presented. The *grouped bar chart* in Figure 2.17...
Figure 2.17  Global sources of power during the period 1990 – 2008.

Note: I added patterning because the adjacent colors are similar if printed in grayscale.
Pie charts

When all components contribute more than two percent each to the whole and your intent is to convey a general impression — not to extract quantitative data — it is possible to present the data as a pie chart (circle chart). If quantitative information must be conveyed, present the data in a table or bar chart, or include the quantitative data in the pie chart as shown in Figure 2.19.

Figure 2.19 2011 Renewable power production. Not shown is tidal/wave power, which produced 0.5 GWh.

2.6 Presenting scientific data: figures, images, and graphs

Figure 2.20 The extent of reaction of ammonia synthesis: \( \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \)

While the reaction favors products at low temperatures, the reaction is kinetically hindered at low temperatures. The colored patch indicates the conditions used industrially to synthesize ammonia, which is a compromise between yield and reaction rate.
2.7 An introduction to statistical analysis

This section both introduces statistical data analysis tools and illustrates the use of equations, figures, and tables in scientific documents. It is not within the scope of Communicating Science to present all possible applications of statistics in science. The application differs across disciplines because the nature of the data differs. Individual disciplines may have one or more courses on the application of statistics within their particular discipline. This section assumes the data is normally distributed.

Most scientific studies and experiments produce quantitative (numerical) data by measuring the effect of individual variables affects a phenomenon. Interestingly, data collected under the same conditions does not return the same numerical data every time. There is variability in the data due to uncontrolled variables in the study/experiment. Statistics provides tools to analyze the data and identify meaningful relationships between the variables and the phenomenon.

Section 4.4 (Research methods) presents the scientific method framework, including details on hypothesis development and method development that lead to data collection. This section focuses on the statistical analysis of data.

The foundation of statistical analysis are the null hypothesis and alternate hypothesis. The null hypothesis, $H_0$, assumes that a variable has no effect on the phenomenon. The alternate hypothesis, $H_a$, assumes that a variable affects the phenomenon.

The goal of the study/experiment is to statistically determine the effect, if any, of the variable on the phenomenon. The researcher either accepts or rejects the null hypothesis based on the results of the statistical analysis... redacted in preview...
Anomalous data

When collecting data, you may have one or more data points that do not follow the apparent trend. You cannot arbitrarily choose to exclude data! You can only exclude data under two conditions:

1. something happened to the sample that could have affected the results (spilled, contaminated, etc.) and this is documented in your laboratory notebook

   *Laboratory notebook*: sample 8 may have been contaminated when <chemical> accidentally spilled and splashed into my work area.

   *Laboratory notebook*: data collected after 10:20 PM may have a systematic error because the detector was bumped and had to be realigned.

2. a data point fails a statistical retention test (see below).

If data points do not follow the apparent trend, it is possible that there were uncontrolled variables in the experimental method or that something else is occurring. Exploring anomalous results may lead to new discoveries.

Rejecting data (Q-test)

Given \( n \) measurements of a sample, if one data point is distant from the other data points — an outlier — the Q-test may be used to determine if the outlier can statistically be rejected. \( Q_{\text{calc}} \) is calculated from the experimental data and measured against \( Q_{\text{tab}} \). \( Q_{\text{tab}} \) is a statistical measure of the probability that \( Q \) would happen — that one data point could be distant from the remainder — by chance at a given confidence level.

\[
Q_{\text{calc}} = \frac{\text{gap}}{\text{range}} = \frac{|\text{suspect} - \text{nearest}|}{\text{largest} - \text{smallest}}
\]

... redacted in preview ...
Table 2.4  Values of $Q_{tab}$ for $n$ measurements at common confidence levels.

<table>
<thead>
<tr>
<th>$n$</th>
<th>68%</th>
<th>90%</th>
<th>95%</th>
<th>98%</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.822</td>
<td>0.941</td>
<td>0.970</td>
<td>0.988</td>
<td>0.994</td>
</tr>
<tr>
<td>4</td>
<td>0.603</td>
<td>0.765</td>
<td>0.829</td>
<td>0.889</td>
<td>0.926</td>
</tr>
<tr>
<td>5</td>
<td>0.488</td>
<td>0.642</td>
<td>0.710</td>
<td>0.780</td>
<td>0.821</td>
</tr>
<tr>
<td>6</td>
<td>0.421</td>
<td>0.560</td>
<td>0.625</td>
<td>0.698</td>
<td>0.740</td>
</tr>
<tr>
<td>7</td>
<td>0.375</td>
<td>0.507</td>
<td>0.568</td>
<td>0.637</td>
<td>0.680</td>
</tr>
<tr>
<td>8</td>
<td>0.343</td>
<td>0.468</td>
<td>0.526</td>
<td>0.590</td>
<td>0.634</td>
</tr>
<tr>
<td>9</td>
<td>0.319</td>
<td>0.437</td>
<td>0.493</td>
<td>0.555</td>
<td>0.598</td>
</tr>
<tr>
<td>10</td>
<td>0.299</td>
<td>0.412</td>
<td>0.466</td>
<td>0.527</td>
<td>0.568</td>
</tr>
<tr>
<td>12</td>
<td>0.271</td>
<td>0.375</td>
<td>0.425</td>
<td>0.480</td>
<td>0.518</td>
</tr>
<tr>
<td>14</td>
<td>0.250</td>
<td>0.350</td>
<td>0.397</td>
<td>0.447</td>
<td>0.483</td>
</tr>
<tr>
<td>16</td>
<td>0.234</td>
<td>0.329</td>
<td>0.376</td>
<td>0.422</td>
<td>0.460</td>
</tr>
<tr>
<td>18</td>
<td>0.223</td>
<td>0.314</td>
<td>0.358</td>
<td>0.408</td>
<td>0.438</td>
</tr>
<tr>
<td>20</td>
<td>0.213</td>
<td>0.300</td>
<td>0.343</td>
<td>0.392</td>
<td>0.420</td>
</tr>
</tbody>
</table>

**Data transformation**

In most cases, you must mathematically transform your raw data into the quantity of interest, such as converting from absorbance to concentration. It is important to convert each data point to a final value before statistically analyzing the data. Why? Because non-linear mathematical operations (square root, power, logarithm, etc.) skew the distribution of the results. *There is a difference* if each data point is transformed to the final value and then averaged or if the raw data is averaged and then ...

... redacted in preview ...
The **mode** is the most frequently observed value, but can only be determined in large data sets.

**Standard deviation**

Standard deviation, \( s \), is a measure of the precision of a single data point in a set of data points obtained by taking replicate measurements of a sample. The standard deviation may be thought of as the range in which we expect the next observation to be found with a certain confidence.

\[
s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}
\]  

**Degrees of freedom**

The concept of degrees of freedom (d.f.) refers to the number of independent values in a calculation. Every statistical calculation reduces the degrees of freedom by one.

Given \( n \) measurements, there are initially \( n \) degrees of freedom.
- Calculating the average removes one degree of freedom.
- Calculating the standard deviation removes another degree of freedom.
  (Note the \( n - 1 \) in Equation 2.8.)

**Reporting of statistics**

Two methods for reporting the statistics of a data set are commonly used.
1. Confidence interval (uncertainty)
   - reports the confidence interval at a fixed confidence level
   ... redacted in preview ...
Method 1: Confidence interval

In addition to calculating the average and standard deviation, it is possible to calculate the range that encompasses the true value with a statistical confidence. Multiplying the standard deviation by a factor $t$ (often called Student’s $t$) determines the confidence interval ($\Delta x$, uncertainty) of the average.

$$\Delta x = \frac{t \cdot s}{\sqrt{n}} \quad 2.9$$

The true value, $\mu$, is within the confidence interval at the stated confidence level (CL).

$$\mu = \bar{x} \pm \Delta x \quad 2.10$$

Table 2.5 lists two-tailed $t$-values for varying degrees of freedom at common confidence levels. Two-tailed means that the true value could be greater or less than the average. The true value in Equation 2.10 is reported at the stated confidence level.

If zero is contained within the confidence interval, the null hypothesis is accepted at that confidence level and the variable being measured does not affect the phenomenon. If zero is not contained within the confidence interval, the null hypothesis is rejected and the variable affects the phenomenon.

Polls and surveys often contain a statement like, “The poll/survey is accurate to within three percentage points 19 times out of 20.” Statistically, this statement translates to an uncertainty of $\pm 3\%$ at the 95% confidence level. ($19/20 \cdot 100\% = 95\%$)

... redacted in preview ...

... redacted in preview ...
Table 2.5  Two-tailed $t$-values for varying degrees of freedom at common confidence levels (CL) and $p$-values.

<table>
<thead>
<tr>
<th>d.f.</th>
<th>68%</th>
<th>90%</th>
<th>95%</th>
<th>98%</th>
<th>99%</th>
<th>CL</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.312</td>
<td>2.920</td>
<td>4.303</td>
<td>6.965</td>
<td>9.925</td>
<td>$p$</td>
</tr>
<tr>
<td>3</td>
<td>1.189</td>
<td>2.353</td>
<td>3.182</td>
<td>4.541</td>
<td>5.841</td>
<td>$p$</td>
</tr>
<tr>
<td>4</td>
<td>1.134</td>
<td>2.132</td>
<td>2.776</td>
<td>3.747</td>
<td>4.604</td>
<td>$p$</td>
</tr>
<tr>
<td>5</td>
<td>1.104</td>
<td>2.015</td>
<td>2.571</td>
<td>3.365</td>
<td>4.032</td>
<td>$p$</td>
</tr>
<tr>
<td>6</td>
<td>1.084</td>
<td>1.943</td>
<td>2.447</td>
<td>3.143</td>
<td>3.707</td>
<td>$p$</td>
</tr>
<tr>
<td>7</td>
<td>1.070</td>
<td>1.895</td>
<td>2.365</td>
<td>2.998</td>
<td>3.499</td>
<td>$p$</td>
</tr>
<tr>
<td>8</td>
<td>1.060</td>
<td>1.860</td>
<td>2.306</td>
<td>2.896</td>
<td>3.355</td>
<td>$p$</td>
</tr>
<tr>
<td>9</td>
<td>1.053</td>
<td>1.833</td>
<td>2.262</td>
<td>2.821</td>
<td>3.250</td>
<td>$p$</td>
</tr>
<tr>
<td>10</td>
<td>1.046</td>
<td>1.812</td>
<td>2.228</td>
<td>2.764</td>
<td>3.169</td>
<td>$p$</td>
</tr>
<tr>
<td>12</td>
<td>1.037</td>
<td>1.782</td>
<td>2.179</td>
<td>2.681</td>
<td>3.055</td>
<td>$p$</td>
</tr>
<tr>
<td>14</td>
<td>1.031</td>
<td>1.761</td>
<td>2.145</td>
<td>2.624</td>
<td>2.977</td>
<td>$p$</td>
</tr>
<tr>
<td>16</td>
<td>1.026</td>
<td>1.746</td>
<td>2.120</td>
<td>2.583</td>
<td>2.921</td>
<td>$p$</td>
</tr>
<tr>
<td>18</td>
<td>1.023</td>
<td>1.734</td>
<td>2.101</td>
<td>2.552</td>
<td>2.878</td>
<td>$p$</td>
</tr>
<tr>
<td>20</td>
<td>1.020</td>
<td>1.725</td>
<td>2.086</td>
<td>2.528</td>
<td>2.845</td>
<td>$p$</td>
</tr>
</tbody>
</table>

The following example calculates the copper concentration in a sample of brass at the 95 % confidence level.

Five pieces of brass were analyzed and the percentage of copper in each measured as 93.42 %, 93.86 %, 92.18 %, 93.14 %, and 93.60 % by mass. The data is visualized at right. 92.18 %

... redacted in preview ...
Uncertainties are typically reduced to one significant digit, so the result would be reported as,

“The concentration of copper in the brass is (93.4 ± 0.5) % by mass at the 95 % confidence level.”

or

“The concentration of copper in the brass is (93.4 ± 0.5) % \((p < 0.05)\) by mass.”

Figure 2.22 presents representative data and the confidence intervals thereof. The bottom data set is close to zero. Zero is included in the uncertainty at the 95 and 99 % confidence level, so the null hypothesis is accepted and the variable found to not affect the phenomenon. At the 90 % confidence level, the null hypothesis is rejected, and the variable is found to affect the phenomenon. This illustrates the nature of inductive science experiments: it is impossible to prove a relationship because, at a sufficiently high confidence level, the null hypothesis cannot be rejected. Method 2 explicitly calculates the confidence level where the null hypothesis is not rejected.
Method 2: Level of statistical significance

It is possible to calculate the probability when the uncertainty encompasses zero. At this probability, the null hypothesis is accepted and the deviation of the average from zero is due to random variation of the uncontrolled variables. At any higher probability, the null hypothesis is rejected and the results are significant. This probability is commonly called the level of statistical significance and is reported as a \( p \)-value. Table 2.5 lists the \( p \)-value for the common confidence levels. However, calculation of the \( p \)-value for a specific data set is done by statistics software.

The confidence level and \( p \)-value are mathematically related.

\[
\frac{\text{confidence level}}{100 \%} + p\text{-value} = 1.00
\]

Sources of uncertainty (ANOVA)

The variance is the standard deviation squared.

\[
V = s^2
\]

Variance is additive for normal (Gaussian) distributions, making it possible to determine the magnitude of different sources of uncertainty. This analysis is often called an ANalysis Of VAriance (ANOVA).

Figure 2.23 shows how to analyze a sample to determine how sampling, preparation, and analysis contribute to the total uncertainty. The variance in \( A \) is due to analysis only; the variance in \( B \) is due to analysis and preparation; the variance in \( C \) is the total variance of all processes. The

... redacted in preview ...
Each is an aliquot.

**Figure 2.23** Sample flow-chart for conducting an ANOVA.

**Propagation of uncertainty**

You have probably learned about how significant digits are carried through mathematical transformations (calculations). The significant digits method is a simple, but imprecise, method of estimating the uncertainty in the final value. In statistics, both the data and uncertainty are transformed; this process is called *propagation of uncertainty* (*propagation of error*). Table 2.6 lists the functions for propagating uncertainty (reported as the standard deviation) through common mathematical operations.

**Table 2.6** Functions for propagating uncertainty through common mathematical operations.

... redacted in preview ...
Additional resources …

... on communicating science


... redacted in preview ...
Chapter 3. Fundamentals of learning

Communication is most effective when both the sender and receiver (writer & reader, speaker & audience) are engaged in communicating and in learning.

In order to prepare quality documents and give quality presentations, it is valuable to have an understanding of how people learn. This chapter presents some of the psychological and pedagogical theories that underlie effective learning and effective instruction.

Table 3.1 Common and scientific definitions of knowledge and learning.

<table>
<thead>
<tr>
<th>Common definition</th>
<th>Scientific definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Knowledge</strong></td>
<td><strong>Knowledge</strong> exists as neural networks in the brain.</td>
</tr>
<tr>
<td>consists of the accumulated facts and impressions we retain from previous experiences.</td>
<td></td>
</tr>
<tr>
<td><strong>Learning</strong></td>
<td><strong>Learning</strong> occurs when new connections are formed between neurons, expanding the neural network.</td>
</tr>
<tr>
<td>is the process of increasing knowledge and/or skill.</td>
<td></td>
</tr>
</tbody>
</table>

Knowledge is gained and shared through communication. Clear, coherent, concise, and precise communication facilitates effective and efficient knowledge transfer and learning by others.

Tell me and I will forget; show me and I may remember; involve me and I will understand. — Chinese proverb

Knowing how people learn is of profound interest and importance. The **redacted in preview**
LEARNING

- Constructivist theory of learning
- Bloom's taxonomy
- Perry's model
- nt
- instructional considerations
- level of instruction
- level of learner
- learning strategies
  - learner must want to learn!
  - strategies listed in Figure 3.12
- instructional strategies
  - instructor led → learner led
  - increasing expectations of learner
  - strategies listed in Figure 3.10

sent in this chapter.
3.1 Learning theories

There are several theories of how learning occurs, with educational psychology actively testing and refining the theories and determining their range of application.

Constructivist theory

In academic environments, the constructivist theory is most applicable. The constructivist theory proposes that learning occurs when new experiences and new information integrates into our existing knowledge framework, thereby expanding the framework. While originally an empirical proposal, brain-function research has provided a biophysical foundation supporting the constructivist theory.

To effectively teach a concept, an instructor must ensure the information being presented overlaps with the learners existing knowledge. This often takes the form of solving real-world problems and using learned equations to derive more complex mathematical equations. If there is no overlap, the new information is not retained and no learning occurs.

To effectively learn a concept, a learner must be willing to learn, have a connection with the concepts being presented, and take an active role in learning. Figure 3.2 shows that the more active a learner is in their environment, the more they learn.

![Average retention diagram]

... redacted in preview ...
Self-determination theory

*Self-determination theory* explores the foundations underlying motivation and personality. The theory proposes that people have three universal needs:

- **competence**: the need to possess knowledge and skills
- **relatedness**: the need to associate and interact with others
- **autonomy**: the need to have control over their life

When these needs are supported, a learner attains increasing senses of well-being and initiative. Social and cultural environments can have beneficial or detrimental effects on attaining these needs. Motivation also affects the attainment of these needs. There are two types of motivation:

- **intrinsic motivation** exists when a learner chooses to learn out of an internal interest in the concept. These learners take on tasks because of their personal interest in the task, the inherent challenge, and the satisfaction they derive from completing the task.

- **extrinsic motivation** exists when a learner chooses to learn because of an external factor, such as the achievement of a grade, imposed deadlines, fear of discipline, entrance into medical school, getting on the honor roll, etc.

In general, intrinsic motivators tend to increase the attainment of the universal needs, while extrinsic motivators either neutrally affect or are detrimental to the attainment of these needs.

For any given learning opportunity, a learner has both intrinsic and extrinsic motivators, and the number of each motivator may change during the learning process. Additionally, extrinsic motivators can change into intrinsic motivators.

... redacted in preview ...
Learners often initially choose a university major because of an extrinsic motivator, “I’m going to be an engineer/lawyer/physician/etc. like my <close family member>.” Learners often change their major to something they are intrinsically interested in.

Many of you — people reading this right now — had a career path planned out, and you now have doubts. This is normal! Many subjects are not taught in high school, so a university course in anthropology, biochemistry, psychology, sociology, and other subjects is your first exposure to these disciplines, and you may fall in love with them. This love is the heart of intrinsic motivation.

To optimize success in learning, learners must maximize intrinsic motivators. They must decide they want to learn for the pleasure and challenge of learning new material. A goal of instructors is to gauge the level of the learners and set challenging but attainable outcomes and assessments. For any given assessment, some learners may find the exercise easy and others may find the exercise challenging. This is the nature of diverse learners. Instructors provide supplemental resources for struggling learners, and encourage advanced learners to challenge themselves with more challenging problems, including directing them to other courses and research opportunities.

To look closer at the idea of extrinsic and intrinsic motivators, consider deadlines. Imagine being well into your career and being asked to write a book on your work. A deadline is set for the drafts and the final version of the book. Early in the writing project, these deadlines are extrinsic motivators, “must get the book done by the deadline”. However, as the book comes together and you receive positive feedback, the deadlines become more of a goal — to have the book done so that it becomes... redacted in preview ...
Self-regulated learning

Related to self-determination theory is the idea of *self-regulated learning*, which is a strategy for learners to actively control their thoughts, behaviors, and emotions so they focus on and optimize their learning. Self-regulated learners have a high degree of *metacognition* (thinking about their own thought processes). The learning process can be divided into three stages. A learner is expected to

1. *prepare*: identify what learning needs to occur, set a plan and timetable to complete the learning, and establish an emotional state where the learner wants to learn

2. *perform*: have the self-discipline to focus on task, monitor their successes and struggles, and adapt their learning strategies to more effectively and efficiently learn

3. *reflect*: review their performance after completing the task, identify factors that reduced performance, and modify their learning strategies for future learning opportunities

<table>
<thead>
<tr>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Self-control</strong></td>
</tr>
<tr>
<td>• applying strategies</td>
</tr>
<tr>
<td>• self-discipline</td>
</tr>
<tr>
<td>• time management</td>
</tr>
<tr>
<td><strong>Monitoring</strong></td>
</tr>
<tr>
<td>• recording learning activities</td>
</tr>
<tr>
<td>• varying learning strategies</td>
</tr>
</tbody>
</table>

... redacted in preview ...
A highly self-regulated learner learns quicker, more efficiently, and better understands the material. This learner does better academically, has a better opinion about learning, and is generally more successful in their career, where independent life-long learning is expected.

Becoming a self-regulated learner is itself a learned activity. Discovering that a person does not learn effectively often begins with poor performance or failure. For example, first-year university students were often not challenged in high school and never learned how to effectively and efficiently learn and study. First-year post-secondary is challenging because of the faster paced material, greater academic expectations, greater student independence, and the lack of effective learning skills.

Self-regulation is a semi-conscious process. A low self-regulated learner is *impulsive* and easily distracted from learning. They will abandon learning when a more enjoyable activity is available: food, television, surfing the internet, a night out with friends, etc. A high self-regulated learner is *dedicated*, and knowingly focuses on learning despite other more-interesting opportunities. They review what they learned daily, begin homework when it is assigned, and have term projects done early so they can review and revise them before submission.

Low and high self-regulated learners exhibit differences in their perceptions on the difficulty of material and in their learning strategies.

- Low self-regulated learners tend to bypass the *preparation* stage and begin at the *performance* stage. When they struggle to learn new information, they tend to blame their lack of ability rather than attempting alternative learning strategies, and they often abandon the learning activity.
  - “I dropped <course> because I’m not good at it.”

... redacted in preview ...
Brain function research is a very active field. The development of real-time MRI has provided researchers with a powerful tool to explore structure-function and activity-function relationships within the brain.

The brain is composed primarily of neurons, which are cells responsible for processing, transmitting, and storing information. Neurons contain

- **dendrites**, which receive signals from other neurons
- an **axon**, which propagates signals within a neuron
- **synaptic terminals**, which transmit signals to other neurons

The *synapse* is the region between a synaptic terminal on one neuron and a dendrite on another. It is still not well understood how a neuron knows which neuron it is receiving a signal from or how it selects which neuron to transmit the signal to. It is known that *learning* is the formation of connections between neurons, which leads to the development and expansion of *neural networks*. 

... redacted in preview ...
Kolb’s learning model

Dr. David Kolb is an educational theorist at Case Western Reserve University. In 1985, he developed a model for how people learn. Kolb proposes that a person cycles through four stages when learning:

• abstract hypothesis (planning)
• active testing (experimentation)
• concrete experience (observation)
• reflective observation (review and analysis)

Dr. James Zull, a biologist also at Case Western Reserve University, discovered a link between Kolb’s model and the regions and pathways in the brain. Zull’s work provides a biophysical foundation for Kolb’s model, which is presented in Figure 3.5.
A person cycles through all of the stages as they learn. However, most people prefer one stage more than the others.

Kolb also proposed learning styles as the transition between the stages.

- **converging**: abstract hypothesis $\rightarrow$ active testing
- **accommodating**: active testing $\rightarrow$ concrete experience
- **diverging**: concrete experience $\rightarrow$ reflective observation
- **assimilating**: reflective observation $\rightarrow$ abstract hypothesis

Figure 3.6 illustrates the four learning stages and four learning styles. Assessments are available for people to determine and visualize their preferred learning stage(s) and style(s).
The *diverging* style involves looking at things from different perspectives. People watch rather than do and tend to gather information and generate ideas (brainstorm) to solve a problem. (Common careers include social work, acting, literature, and journalism.)

The *assimilating* style involves taking a concise, logical approach to solving a problem. People take information and organize it logically, focusing on ideas and abstract concepts. (Common careers include science, mathematics, and law.)

The previous pages list careers of people who prefer a given learning style, but these people must be functional in all the learning styles to be good in their career. *Practice* is required to become comfortable at all four learning styles. This practice can be in the form of a hobby: scientists who exercise and socialize develop their accommodative and divergent learning styles.

Adept learners are comfortable in all four learning stages. Weakness at any stage introduces barriers to learning.

**Learning**

At birth, the brain has rudimentary neural networks to perform basic functions: breathing and circulation. Everything else is learned: muscle control, language, social interaction, etc. For example, an infant has very limited voluntary muscle control. Through random activation of neural pathways, an infant learns to suckle and move their fingers, arms, legs, and other parts of their body. If the neural pathway leads to a productive motion (suckling to receive milk, for example), the motion is repeated and the neural pathway reinforced. If the neural pathway is non-
4. The temporal cortex determines that the hand did not extend far enough, missing the toy.
5. The infant hypothesizes that by extending their hand further, they can reach the toy.
6. … the cycle repeats …

Learning is a process. The first exposure to new information or to a new action begins neural network development. Repeated use of the neural network strengthens the pathways. The more the pathways are used, the better the information or action is learned. Use also creates pathways to related information that further expands the neural network and increases knowledge. Technically, this process is called long-term potentiation. If unused, the pathway degenerates and knowledge is lost.

Consider:
- Watching baseball games does not mean you can hit a baseball.
- Watching an instructor solve a math problem does not mean you can solve one.
- Watching a nurse administer an IV does not mean you can do it.
- Reading a well-written novel does not make you a writer.

In each case, the professional — athlete, instructor, nurse, writer — completes the task with relative ease. These people have practiced these skills many, many times. They have developed extensive neural networks that activate when required. By watching their actions, you have started neural network development — the first step in the learning process. Practice is required and critical to become proficient at any task.

<table>
<thead>
<tr>
<th>Experts think differently than novices</th>
</tr>
</thead>
<tbody>
<tr>
<td>... redacted in preview ...</td>
</tr>
</tbody>
</table>
Applying this to post-secondary instruction: professors typically teach material in a way that makes sense for them — how they understand the material. This may not be the best method as their understanding was developed after years of dedicated study, which the student has not completed and may not be interested in completing. It requires significant effort to produce instructional material that presents information in a way conducive to student...
<table>
<thead>
<tr>
<th>structor led (self-directed learner)</th>
<th>Guided inquiry</th>
<th>Learner led (self-directed learner)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner uses question posed by instructor.</td>
<td>Learner refines question posed by instructor.</td>
<td>Learner poses question.</td>
</tr>
<tr>
<td>Learner given procedure.</td>
<td>Learner given framework for procedure.</td>
<td>Learner told what data is needed and develops procedure.</td>
</tr>
<tr>
<td>Learner is aided with collection.</td>
<td>Learner sets up equipment and collects data with supervision.</td>
<td>Learner sets up equipment and collects data.</td>
</tr>
<tr>
<td>Learner given steps to analyze data.</td>
<td>Learner given framework for analyzing data.</td>
<td>Learner told what information is required and formulates strategy.</td>
</tr>
<tr>
<td>Learner told connections to scientific knowledge.</td>
<td>Learner given possible links to scientific knowledge.</td>
<td>Learner directed toward areas and sources of scientific knowledge.</td>
</tr>
<tr>
<td>Learner answers questions posed by instructor.</td>
<td>Learner answers questions in report format.</td>
<td>Learner informed what areas to cover in report.</td>
</tr>
</tbody>
</table>

Guided inquiry

<table>
<thead>
<tr>
<th>Fundamentals of learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Science Education Standards, Table 2.6,</td>
</tr>
</tbody>
</table>

graduate school

undergraduate education

grade school
Working and long-term memories

Psychology research proposes that the brain has a *working memory* that stores information relevant to solving the problem and a *long-term memory* that is the collection of our knowledge. A person can store between three and seven bits of information in their working memory. Recall from long-term memory is rapid, transparent, and limitless.

There has long been a debate amongst educational researchers about what needs to be memorized and what can just be looked up. For example, it was argued that, because of calculators, people did not need to memorize multiplication and division tables. In schools, memorization was devalued and calculators introduced much earlier. The long-term result: students are poorer at mathematics. The limited capacity of the working memory explains why. If memorized, the simple arithmetic results can be recalled from long-term memory to complete more complex mathematical problems. When not memorized, the simple arithmetic occupies some of the spaces in the working memory, increasing the challenge of solving the complex problem. Learners are less capable at mathematics and perceive it to be harder. (Yes, this is still a problem.)

To illustrate a growing neural network, consider the progression of learning and applying mathematics.

- Learning numbers and to count
  - learning addition and subtraction
  - learning multiplication and division
  - learning that variables represent numbers
    - learning powers, exponents, and logarithms
    - learning geometry, trigonometry, and algebra
    - learning calculus
    - learning pure mathematics

... redacted in preview ...
3.3 Considerations when teaching and learning

Bloom’s taxonomy

_Bloom’s taxonomy_ is a method of categorizing assessments and instructional activities. Bloom defined three learning domains:

- **cognitive domain**: working with information
- **affective domain**: working with emotions
- **psychomotor domain**: working with tools or instruments

Within each domain, there is a progression from simpler low-level activities to complex high-level activities. For every subject, a learner progresses through these levels as they learn the subject.

<table>
<thead>
<tr>
<th>high</th>
<th>create</th>
<th>characterize</th>
<th>naturalize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>evaluate</td>
<td>organize</td>
<td>articulate</td>
</tr>
<tr>
<td>level</td>
<td>analyze</td>
<td>value</td>
<td>precision</td>
</tr>
<tr>
<td></td>
<td>apply</td>
<td>respond</td>
<td>manipulate</td>
</tr>
<tr>
<td>low</td>
<td>understand</td>
<td>receive</td>
<td>imitate</td>
</tr>
<tr>
<td>domain:</td>
<td>COGNITIVE</td>
<td>AFFECTIVE</td>
<td>PSYCHOMOTOR</td>
</tr>
</tbody>
</table>

**Figure 3.9**  Bloom’s learning domains and the progression of learning activities within each domain.

For example, a grade 8 student who has just been introduced to algebra would not be able to solve Schrödinger’s equation for a particle in a... redacted in preview...
3.3 Considerations when teaching and learning

Bloom’s cognitive taxonomy

**common keywords**
assemble, derive, design, develop, devise, formulate, speculate, transform, theorize
adapt, appraise, consider, debate, defend, estimate, grade, justify, select, support
categorize, discriminate, devise, distinguish, examine, interpret, plan
complete, demonstrate, illustrate, operate, plan, predict, use
classify, compare, describe, discuss, express, summarize
define, identify, list, match, reproduce, select, state

**in science**
design new experiments
critique an experiment; propose modifications
analyze data to extract information
solve a problem; conduct an experiment
explain a concept in other terms
recall information

**Figure 3.10** Expansion of Bloom’s cognitive domain to illustrate the verbs used at each level and in application to conducting an experiment. Some verbs may be used in other categories, depending on the context of the question.

Clark* applied Bloom’s taxonomy to instructional strategies. The results are presented in Figure 3.11. Effective teaching requires that the instructor and learner progress from lower-level to higher-level instruction. The lower-level instructional strategies tend to be passive (instructor-centered) while the higher-level strategies are active (student-centered). The highest level of instruction is *self-directed learning*, but without the commitment of the learner to learn on their own, they will never reach this level. That is, the learner must take personal interest and ownership in their learning. These people excel academically and in their careers. (Learner levels are presented on page 137.)

... redacted in preview ...

... redacted in preview ...
An instructor teaching a class of mostly passive learners and/or extrinsically motivated learners (introductory courses) must begin with low-level instructional strategies and progress upwards. Very likely, the instructor will primarily use the lowest two levels. An instructor teaching advanced learners and/or learners who have similar interests (senior undergraduate and graduate courses) will be able to use higher-level instructional strategies.

Most introductory science courses have laboratory components, and students are often confused and/or frustrated because they do not see the connection between laboratory and classroom instruction. This is consistent with educational psychology because hands-on activities (laboratory experiments) are a high-level instructional strategy and

... redacted in preview ...
Learner development

Divisions within sociology, psychology, and psychiatry focus on research, application, and educating people about learner development. This section focuses on the development of learners in an academic environment and is based on two models of learner development. The terminology and focus have been adapted to be consistent with this chapter.

Learners progress from a simplistic, categorical view of the subject to a realization that both knowledge and values are involved in decision making. There are four stages of learner development.

**Passive learners** expect to receive all the information they are required to learn from the instructor. They believe that there are obvious solutions to all problems. They expect to be taught how to determine the “correct” solution, and perceive instructors as having and disseminating the “correct” solutions. Knowledge is perceived as known and absolute.

**Active learners** participate in instructional activities at the direction of the instructor. They realize that there may be multiple perspectives from which to analyze a problem, but struggle with the idea of multiple “correct” solutions. They do not understand and are frustrated with instructors who wants a particular solution and justification for that solution. Knowledge is perceived to be contextual and subjective since it is colored by a person’s beliefs.

**Engaged learners** go beyond the minimum assigned learning activities. They prepare for class, read additional material on the topic, and complete additional exercises for their personal interest and to better their understanding. They make connections between concepts learned in different courses. They no longer expect instructors to give them the... redacted in preview...
**Self-directed learners** independently identify and investigate concepts of personal interest. Their primary desire is to increase their knowledge. They are able to develop understanding and a solution after independently considering the available information. They are willing to defend their solution, debate the merits of different solutions, and possibly change their solution based on new information. Instructors are perceived as a source of expertise and as peers. Knowledge is perceived as the result of focused and critical analysis of the available information, and the applicability of that knowledge in other contexts.

*A teacher is one who makes himself progressively unnecessary.*

Thomas Carruthers

When learning a new subject, every learner starts as a passive learner. At each stage, learners progress from being *marginal*, to being *adept*, to being *impeded* by the stages’ limitations. Being impeded facilitates/forces learners to transition to the next stage. The progression through the stages is irregular and generally difficult as more responsibility for learning is placed on the learner at every stage. A person’s interest, effort, and their willingness to learn determines where they end. The adept self-directed learner is the pinnacle of intellectual development because the learner has the intellect to independently investigate and understand a concept, the ethical development to weigh the consequences of a decision, the willingness to make and defend a decision, and the openness to consider alternatives.

For example, most of the public are passive learners when considering science. They believe what they are told: that there is a single correct solution to scientific problems, and they are confused by conflicting arguments presented by scientists, industry, government, etc. Most
Consider the following activities:
• purchasing a vehicle
• listening to a politician
• having to go to court

If these are not activities you do regularly, they make you uncomfortable. The people familiar with these events exude confidence — salesmen, politicians, police, lawyers — and you find yourself trusting them. But very often, these people are not acting in your best interests. The more times you experience them, the more you see through the façade. This is one reason your parents are more cynical about politicians than you.

Instructors should teach in a way that presents an understanding at the given level and that can be built upon in future classes. Only once you have taken the future courses can you assess the quality of instruction of your previous courses.

The progression of understanding

Complementing the progression of the learner from passive to self-directed is a progression in understanding.

What is meant by understanding a concept?
• Being able to restate the concept? (alphabet, multiplication tables)
• Being able to apply it? (communication, algebra)
• Being able to develop it? (novels, poetry, calculus, derivations)

Understanding increases as a learner progresses through these stages. Figure 3.12 presents a progression of understanding.
Progression to knowledge and wisdom requires a learner to be at the engaged or self-directed level and requires they apply high-levels of Bloom’s taxonomy (Figures 3.9 and 3.10) to their learning.

**Optimizing learning**

The learner — no one else — determines how much learning occurs.

Figure 3.2 lists two types of instructional activities: passive and active. These correlate with the passive and active stages of learner development presented above. The final two stages — engaged and self-directed — are stages intrinsic to the learner. Only the learner can decide if they progress to and through these stages. Instructors can create environments conducive to learning and present information using optimal instructional strategies, but if the learner is not interested, no learning occurs and the learner does not progress. Indeed, the more ownership a learner takes in learning, the more they will learn and be prepared to learn in their future courses and careers.

Three types of learning are commonly observed.

**Surface learning** occurs when a learner focuses on memorizing new information, rather than linking it to their existing knowledge. This often occurs when the learner is not interested in a subject and endeavors to complete the minimum requirements in the course. The information is easily forgotten because there are few links to existing knowledge. For example, students who take notes verbatim and cram for exams are surface learning. Outside of academia, surface learning is used by people... redacted in preview ...
Strategic learning occurs when a learner selects which information to deep learn and which to surface learn. For students taking courses, this is a risky strategy as the instructor controls the course emphasis. Learners, by definition, do not fully understand the intricacies of a subject and therefore are ill-prepared to decide what information is relevant. Successful strategic learning requires a large knowledge base from which to identify the important advanced concepts. Strategic learning may be successful for self-directed learners who are able to chart their learning objectives. Outside of academia, strategic learning occurs regularly. People with a special interest will learn information to satisfy that interest. The interest could be about something they heard, warranty or insurance information, criminal proceedings, etc. People expanding their work-related knowledge will strategically learn information.

Surface learning typically occurs when a learner is extrinsically motivated and a passive learner. Deep learning and strategic learning occur when a learner is intrinsically motivated and at the active, engaged, or self-directed stage.

All learning starts as surface learning. For example, learning multiplication tables and the amino acids. Surface learning transforms into deep learning when the learner looks for patterns and insights into how information is connected and applied. Advanced learners combine these activities, so move directly to deep-learning.

For example: linking the multiplication tables to counting-by-numbers and to formulae in science courses; and linking amino acid functional groups to hydrophobic and hydrophilic regions, and to the secondary and tertiary structure of proteins.

... redacted in preview ...
Figure 3.14 lists numerous learning strategies to enhance learning. Other resources provide details on how to implement these strategies.

In addition to learning information, you must also learn to recall information so that you can recall it when required: on exams, in future courses, in interviews, and in careers. The use of cue cards forces you to recall information randomly. At a higher level, teaching (formal and informal) requires you to recall information, formulate a coherent response, and present that information clearly and concisely.

Teaching is the conveyance of information in a mode that facilitates learning.

Learning is the integration of information leading to an increase in knowledge and/or skill.

Figure 3.13 The complementary relationship between teaching and learning.

In the context of Communicating Science, knowing how people learn allows us to prepare documents and presentations that convey information in a manner conducive to learning.

... redacted in preview ...
Learning Strategies

- notetaking
- writing in your own words
- questioning
- build context & applications
- mnemonic
- concept mapping
- brainstorming
- peer study & instruction
- comfortable learning environment
- regular practice & studying
- time management
- focus on learning

Learners control their learning!
Learner engagement dictates
the creation and expansion of neural networks.

Increased knowledge

Learning Strategies

- direct
- meta

Learning Strategies

- incoming knowledge
- notetaking
- writing in your own words
- questioning
- build context & applications
- mnemonic
- concept mapping
- brainstorming
- peer study & instruction
- comfortable learning environment
- regular practice & studying
- time management
- focus on learning

Focus, Prioritize

and never give up
on things you want.
Additional learning considerations

Psychological and pedagogical research continues to identify factors that enhance and impede learning. Below are some recent findings.*

**Multitasking.** The brain functions optimally when focused on a single task. The brain is poor at multitasking when the same region of the brain is required for both tasks. For example, reading a textbook and watching television both require the vision and language procession regions of the brain. Using a laptop in class reduces learning by over 20%. Listening to music *with* lyrics also degrades learning. However, listening to music *without* lyrics stimulates the brain and improves learning.


**Taking notes.** Students who handwrite notes take more concise notes and deep-learn the material better than students who take notes on a computer. Additionally, students who handwrite notes do better on assessments. One survey found an average increase of 18% for students who handwrite notes.


**Practice makes permanent.** A person’s skill correlates with the amount of practice they do. Willingham argues there is no such thing as a prodigy, just people with a faster rate of skill development; prodigies too improve with practice. Importantly, learning incorrect information or practicing an technique improperly will embed that incorrect knowledge, making it exceedingly difficult to correct.

Source: Willingham DT. Practice Makes Perfect — but Only If You Practice Beyond ...

... redacted in preview ...
3.3 Considerations when teaching and learning

decreases substantially after approximately 60 minutes of instruction. Before being able to learn more, a student must take time to process the information they have into knowledge. That is, cramming and long classes are poorer learning strategies.

Taking multiple courses also allows the person to more broadly expand their neural network, with links forming across all of their courses.


Digital amnesia. Increased use of technology is resulting in people memorizing less information. Information is stored on electronic devices and looked up online. The reduced use of the storage and recall regions of the brain results in increased difficulty memorizing information, recalling information, and an overall decreased cognitive ability because the information must occupy the limited space of the working memory.


Optimizing instruction

Bloom’s taxonomy classifies the assessment and instruction. The learner development models classify the learner.

Effective instruction — instruction that facilitates the most knowledge in the learner — requires that both Bloom’s taxonomy and the learner level be considered when deciding on instructional strategies and assessments.

... redacted in preview ...
Figure 3.15 The inherent challenge of instructional strategies and assessments for learners at different levels of development.

Instructors should use instructional strategies from Figure 3.11 to create an active and engaging instructional environment. The selection should correlate to the possible and inherently challenging categories for the learner group. Figure 3.16 presents the progression of a learner’s preference of instructional strategies as they develop academically. For instructors, it is important to challenge learners to facilitate their transition to the next level.
Typical instruction patterns

Instructors typically use instructional strategies that mirror their preferred learning style(s): they teach the way they learn. Students find learning easier when

• the instructor and student have similar learning styles (see Figure 3.6)
• the information being taught overlaps with the student’s existing knowledge
• the student is interested in the information
• the instructor uses instructional strategies consistent with the learner’s level

When any of the above are not present, learning is more difficult.* The student can still learn, but will feel somewhat frustrated. These are excellent opportunities for students to develop other learning styles. For instructors, teaching in an alternate style improves their ability to teach and learn in that style.

A significant problem occurs when a person learns incorrect information. The more layers of information built on incorrect information — the more neural networks that link to the incorrect information — the harder it is to correct the erroneous information. From an educational perspective, in order to achieve the greatest understanding, students must be taught truthful information in a manner that allows future learning to build upon that information. For example, some high school chemistry instructors teach that there are “seven different types of chemistry problems” and then teach ways of identifying the type of problem and their solutions. While this strategy may work with the simple problems students face in high school, it introduces a misconception that chemistry is strictly algorithmic, which limits the students’ ability to apply what

... redacted in preview ...
3.4 Reading for understanding

Reading for pleasure is simple and enjoyable. Consider a novel, you read from the first page to the last, usually at a steady pace. After you have finished the novel, you are able to explain the overall story, but you do not recall many of the specific details. When reading for pleasure, you retain an average of 10% of the details, as illustrated in Figure 3.2.

Reading for understanding requires a different approach and different mindset to optimize learning. This section focuses on reading academic works (textbooks, scholarly articles, etc.), but can also be applied to literary works (novels, plays, etc.) used in academic courses.

Academic works do not all have the same purpose. Textbooks are designed to present information to persons learning the material. Scholarly articles are designed to present information to other experts. The strategy to optimize learning from each differs slightly.
Activate your brain: talk to yourself and question yourself

Talking to yourself when reading makes the process active. Reading is a passive process, activating only the visual and memory regions of the brain. Talking activates the motor region, and listening activates the auditory region. Reading aloud increases brain activity as there are more inputs of the same information, which builds and reinforces diverse neural connections, improving learning.

As you read the text aloud, also ask yourself
- How does this explain or link to <another section or concept>?
- Can I relate this to things I already know?
- How might this be expanded later in the chapter/book/article?
- Where and how can I apply this now? in my career?

Strategies for optimized learning while reading a textbook

1. Establish a learning mindset

Establishing a learning mindset involves willing yourself into a psychological state where you want to learn the material. You are getting psyched! Learning improves when you perceive a subject to be interesting and relevant; when your mind is not distracted by personal problems; and when you are rested, clean, sated, and comfortable.

*The mind is not a vessel to be filled, but a fire to be ignited.* — Plutarch

Strategies to establish a learning mindset include
- telling yourself that this material is interesting and important

... redacted in preview ...
2. Preview the chapter

In a novel, the last few chapters tie together all the threads in the book. The same occurs in each textbook chapter: the key concepts are near the end of each chapter. To optimize learning, it is important to know these key concepts before reading the text — this primes the mind to want to know how and why these key concepts were developed. Then as you read the text, you see how the material builds into the key concepts.

Indeed, academic works are structured to present the key concepts early. In textbooks, the key concepts are listed at the beginning and/or end of each chapter, in the *Overview* and *Summary*, respectively.

Previewing involves skimming most of the chapter, but reading certain sections. Specifically,

1. *read* the *Overview* and/or *Summary* to identify the key concepts
2. *skim* the text, but *read* the following:
   - headings and subheadings (important concepts, and links between them)
   - sentences with emphasized words (important or defined terms)
   - figures and tables, and their captions
   - the final section(s) in the chapter (develops many of the key concepts)

Figures and tables are often overlooked, but should be read thoroughly. They provide information in an alternate form, which is valuable for learning.

During the preview, identify links between the new information, your existing knowledge, and your interests.

3. Actively read the chapter

Knowing the key concepts, *read* the chapter to make and reinforce the ... redacted in preview ...
If you find yourself making connections to things in your everyday life, and/or to things you are learning in other courses, great! This expands and reinforces the neural network in your brain.

Note: if you are applying this learning strategy to a short story or novel, you want to read the entire novel in step 2 and each chapter in step 3.

4. Take regular breaks

Take a break after every chapter and every hour, whichever comes first. Breaks give your mind time to process and connect the new information to your existing knowledge and connect the new concepts to each other.

Since you have been sedentary, get active: run, swim, cycle, lift weights, do yoga, martial arts, etc. Give yourself up to 30 minutes of physical activity for every hour of homework. Avoid watching TV or playing video games. Physical activity improves your state of mind and your health, which improves learning.

If you discover that you just spent hours reading, feel like you have learned a lot, and still feel energized, welcome to the zone. Being zoned in is a psychological state of consciousness where you are completely immersed on a task. Learning is enjoyable and effortless, and is becoming intrinsic (see page 122). The more frequently you zone in to learning, the more enjoyable the learning becomes, the easier it becomes to zone in, and the better you learn the material. 😊

5. Review the material

Read the notes you took. Ensure they are a clear, concise, coherent, and precise summary of the key concepts and links between them. Add

... redacted in preview ...
If chapters build on each other, review your notes on the previous chapter before reading the current chapter so that the information is fresh in your mind and you can build connections across chapters.

Review all your notes weekly to reinforce the developing neural network and to develop links to the new material you are learning. Set up study groups where you discuss and share material, and challenge each other with questions. If you can dynamically recall and formulate answers to random questions on the material, you know it well.

*To teach is to learn twice over.* — Joseph Joubert

**Strategies for optimized learning while reading a scholarly article**

1. **Establish a learning mindset**
   <same as reading a textbook>

2. **Preview the scholarly article**

Like textbooks, scholarly articles are also structured to present the key concepts early. In scholarly articles, the abstract presents this information.

Research follows the scientific method, and scholarly articles often follow the scientific method in presenting the research.

Previewing involves skimming the article and identifying the components of the scientific method. Specifically, identify the

- *observation* that led to the research (in the abstract or introduction)
- *hypothesis* (the word “hypothesis” is not commonly used; look for phrases like, “This research shows …” or “We discovered that …”).

... redacted in preview ...
experiments. However, it is important to read the entire article to obtain a general understanding of the entire academic work.

3. Actively read the scholarly article

The Preview provides you with the key information the article endeavors to convey. Now read the article to make and reinforce the connections between this information. Questions you should answer include:

- Why is the hypothesis interesting and important to investigate?
- Why is the experimental method valid for this research?
- How does the experiment work? What was controlled? What was measured?
- What are the limitations of the experimental method?
- What information is conveyed in the figures?
- How was the data analyzed?
- Do the results support the hypothesis? Is the analysis reasonable and statistically valid?
- What new information does this research add to the scientific field?
- How could the experiment be improved?
- What further experiments could be conducted?
- <any specific questions you have about the research>

Read the article aloud and verbally express your commentary and questions on the article. Underline or highlight information that answers the questions. Focusing on the information you underlined or highlighted, prepare a summary of the article in your own words. Section 5.5 explains how to prepare an article summary.

4. Take regular breaks

... redacted in preview ...
plot and action because you know what is going to happen. You notice additional actions and better understand the movie.

When reading a scholarly article or book, the goal is obtaining a deep understanding of the material. Skimming the material gives you a basic understanding and you learn the key concepts. The second reading reinforces the development of the key concepts and deepens understanding of all the material.

**Concept maps and flowcharts**

In addition to writing notes in paragraph form, you may augment your notes with *concept maps* and/or *flowcharts*.

- A **concept map** is a graphical representation of the concepts and connections between them.
- A **flowchart** is a graphical representation of a workflow or process.

By themselves, they do not contain sufficient detail for in-depth learning, but they do provide an overview of the connectivity between concepts and do break up the text, which is valuable for learning.

A sample concept map is presented in Figure 3.1, and there are several flowcharts in Chapter 5.
3.5 Effective learning and studying strategies

Each of these strategies will improve your understanding of the material. The more strategies you apply, the greater your understanding.

1. Preview the text before class.
   Don’t expect to understand it, just read it. This acquaints you with the information so that the classroom is where you see the material for the second time. You will find yourself saying, “Oh, so that’s what the textbook means!”

2. When reviewing, don’t just read, write and talk!
   Writing and talking are forms of active learning. Taking notes, rewriting your notes, and completing assignments use motor skills that strengthen and expand neural networks. Rewriting your notes (weekly, before exams, and at the end of term) forces you to critically review the information, follow the ‘train-of-thought’ of the instructor, and repeat it in your own words. Importantly, you end up with a smaller but complete set of notes from which to study!
   Prepare cue cards or a ‘super-summary’ of your notes. These contain only the major concepts and key points. When studying, read a key point and then fill in the details in your mind.
   Talking forces you to dynamically formulate your knowledge into coherent statements, again using and expanding the neural networks.
   Working in peer groups (two to six people) is an excellent way to pool and share knowledge. Students often explain concepts in a way that peers can relate to and teaching others is an excellent way to learn.

... redacted in preview ...
4. **Don’t memorize, build associations and learn the big picture.**

Memorization only works for the questions at the lowest level of Bloom’s Taxonomy. As you progress with your education, there will be too much information to memorize and memorization will be insufficient as courses expect you integrate diverse concepts together to analyze, evaluate, and create knowledge.

To better learn material, build links between what you are learning and your existing knowledge. Endeavor to understand how the information integrates into and expands your overall understanding of the subject. Identify applications of the information both within the subject and in everyday use.

5. **Don’t pull ‘all-nighters’.**

Your ability to learn when fatigued is very low. Your mind’s ability to recall information and dynamically formulate answers is faster if you get a good night’s sleep, not live off caffeine, etc.

6. **Don’t study right up to the exam.**

Take at least a four-hour break before the exam. Your mind can better consolidate what you have learned if you aren’t cramming more in. Get active: go for a walk, to the gym, etc. Exercise will refresh your mind and you will be able to recall information faster.

---

**Exam “cheat sheets”**

Some instructors allow students to bring a “cheat sheet” — a piece of paper (or index card) with whatever information they want on it.

... redacted in preview ...
3.6 A process to maximize exam grades

1. **Read the exam start to finish.**

   This should take no more than a few minutes but will give you an overview of the entire exam. Your mind will unconsciously begin processing all the questions. Some instructors even give hints/answers to some questions in other questions. How many times have you been stumped on a question during the exam and then, while walking away, had a revelation on how to answer it. You weren’t thinking about it, were you? Now consider if your mind had been unconsciously processing that question for a while longer (like from the start of the exam).

2. **Go through the exam and answer questions you know ‘by heart’**.

   Your train-of-thought should be, “One: I know how to do this ... <answer>. Two: not a clue. Three: hmmm, not really sure. Four: oh yeah, that’s how four is done ...<answer>. Five: like this ... <answer>. Six: …”

   Rereading the questions will keep your mind working on them. When the revelation strikes: “Oh yeah, that’s how question three is done!”, go back and complete three while it is still fresh in your mind. If you are stuck on a question, move on to the next one.

3. **Write something for questions you haven’t tried yet.**

   Some questions will be complex, and there may be more than one path to the correct answer. Writing may spark an idea. Try rewriting the question in your own words and jotting down ideas. Don’t be afraid to write something that may be wrong. If nothing else, putting something ... redacted in preview ...
Additional resources …

... on constructivist learning


... on self-determination theory


... on self-regulated learning

Zimmerman BJ. Becoming a self-regulated learner: An overview. Theory Into Practice, 2002;41:64–70.


... learning and the brain


Persons wishing to determine their preferred learning style(s) can find several learning styles assessments online.

... on Bloom’s taxonomy ... redacted in preview ...
... on learning models


Finster DC. Developmental instruction: Part II. Application of the Perry model to general chemistry. Journal of Chemical Education. 1991;68(9),752.

King PM. Reflective Judgment [internet]. Available from www.umich.edu/~refjudg/


... redacted in preview ...
Chapter 4. Research methodology

*If we knew what it was we were doing, it would not be called research, would it?*

Albert Einstein

*Science* is the systematic study of nature and behavior.

*Research* explores the unknown, with the results expanding the body of human knowledge. (See Figure 1.4 on page 9.)

*Investigation* explores existing knowledge, with the results consolidating and summarizing that knowledge.

For example:

- A person preparing an essay on ozone depletion learns the relevant chemistry and atmospheric physics. This is an investigative project.
- A person joining a research group preparing a review summarizing the research in the field and uses this to decide on their research project. Their review is an investigative project.
- A person reviewing traffic accident data discovers a correlation between the accident rate and a change to the traffic light sequencing. This is a research project.
- An engineer looks up the properties of materials to select the best material for a new product. This is an investigative project.

Scientists conduct *research* to expand our understanding. Scientists, journalists, writers, and others conduct *investigations* to consolidate knowledge and make it understandable to specific groups and the public. *Researcher* is a general term referring to a person conducting either a research or investigative project. Whatever project you conduct, your

* ... redacted in preview ...
4.1 History and evolution of science

The foundations of scientific study were laid over 2500 years ago. Much of the early development in mathematics, astronomy, medicine, and alchemy (the precursor to chemistry) occurred in the Middle East. Some notable philosophers and a few of their contributions are given below.

[6th century CE] Aryabhata recorded the apparent movement of the stars and concluded that the Earth orbited the sun. He also introduced the concept of zero.

[5th century BCE] Pythagoras is the first person known to use a scientific hypothesis, which he did when he proposed the Earth was round.

[5th century BCE] Democritus proposed the existence of atoms and the atomic structure of matter.

[5th century BCE] Socrates contributed to the development of ethics, logic, and pedagogy.

[5th century BCE] Hippocrates studied and described medical conditions and illnesses. He wrote the Hippocratic Oath, still recited by physicians today.

[4th century BCE] Plato founded a school focused on natural philosophy: the study of the natural world.

[4th century BCE] Aristotle proposed deduction as the philosophical approach to scientific research. This became the mainstay of scientific research for nearly 2000 years.

[3rd century BCE] Euclid contributed significantly to mathematics. He is commonly referred to as the Father of Geometry for his work.

... redacted in preview ...
The primary hindrances to scientific advancement were religion* and conquest. Religious doctrines were deemed to be above the people. Questioning them was treated as heresy and was punishable by excommunication or death. Additionally, when one nation overthrew another, the victors often destroyed the libraries, universities, and hospitals — the accumulated knowledge — of the conquered nation.

_The Church says that the world is flat but I know that it is round for I have seen its shadow on the moon and I have more faith in a shadow than in the Church._

Ferdinand Magellan

The scientific revolution

During the 16th and 17th centuries, European scientists made several profound discoveries that advanced our understanding of the world. During this period and with overwhelming evidence to support their results, scholars published views that went against religious doctrine. Many were punished by the church for their work, but this revolution — as much a revolution of advancement as a revolution against the church — established science as a secular activity. Selected notable discoveries are given below.

[1473 – 1543] Nicolaus Copernicus proposed that the sun was the center of the solar system and that the stars were much farther from Earth than the sun.

[1564 – 1642] Galileo Galilei contributed to physics, astronomy, engineering, and mathematics. Among his many contributions, he discovered the first of Jupiter’s moons and showed that bodies fall at the same rate, independent of mass.

... redacted in preview ...
In **induction**, the reasoning is from specific facts to a logical conclusion. That conclusion is one possible result, with other conclusions being possible. Examples of induction include

- the construction of a scientific hypothesis
- the analysis of experimental data
- extrapolation from known results to related systems
- the development of models and theories
- diagnosing an illness based on symptoms

From the conclusions, general principles (hypotheses, theories, models, laws) can be developed.

In **deduction**, the reasoning is from a general principle to specific predictions. If the principle is true, the predictions are true. Examples of deduction include

- the derivation of mathematical equations and proofs
- applying a formula to specific data
- using a model, theory, or law to predict the outcome of an experiment
4.1 History and evolution of science

It is impossible to prove a conclusion true, but possible to prove it false.

This statement is a key aspect of scientific research and a consequence of the inductive nature of scientific research. Scientific results — data — are unchanging facts, but the interpretation of those results may vary from person to person and over time. With additional data and additional analysis, the conclusions drawn by different researchers. In this manner, the body of scientific knowledge is ever-evolving and self-correcting — a strength, and the nature of research!

Modern science

In the 1800s, several experiments were conducted that could not be explained by the then-known laws of physics. Some unexplainable phenomena include

• blackbody radiation
• photoelectric effect
• heat capacity of solids
• discrete atomic spectra

The work done by Newton and earlier natural philosophers is now known as classical physics, and explains much of the world we live in. Three new areas of science were developed in the early 1900s to explain phenomena at smaller and larger scales, and at extreme velocities.*
Some of the major developments during the modern scientific period are listed below.

[1822 – 1895] Louis Pasteur confirmed that germs cause many illnesses.
[1833 – 1907] Dmitri Mendeleev created the modern periodic table.
[1858 – 1947] Max Planck proposed that energy levels were quantized.
[1877 – 1966] Edmond Locard proposed the exchange principle, a foundational basis of forensic science.

Because of the increasing pace of scientific research and rapid development of new knowledge and new technologies, many people consider society today to be in a second scientific revolution.

... redacted in preview ...
4.2 The breadth of science

*Facts are not science, as the dictionary is not literature.* — Martin H. Fischer

Science began as a continuum, and early scientists (also known as *natural philosophers*) studied whatever they were interested in. However, the increasing volume of knowledge meant that it was increasingly difficult for a person to be knowledgeable in all of science and be able to conduct research in multiple areas. The scientific revolution saw the evolution of science into three disciplines of study.

**Biology:** the study of life and of living organisms, including their structure, function, growth, origin, evolution, and distribution.

**Chemistry:** the study of the composition, structure, properties, and reactivity of matter, especially of atomic and molecular systems.

**Physics:** the study of matter, energy, and their interactions, from the fundamental building blocks of matter to interstellar interactions.

A person could become reasonably knowledgeable in a single discipline and an expert in one aspect of that discipline. However, an unintended consequence of this division was that there was less and less contact between biologists, chemists, and physicists. The disciplines were becoming silos of knowledge. In the 1970s, it was observed that much advancement was occurring at the interface between disciplines. *Biochemistry, environmental science, physical chemistry,* and numerous other disciplines were active areas of interdisciplinary research.

**Reclassification of science**

... redacted in preview ...
Life science is the study of organisms, living or not.*

- biochemistry • biology • botany • ethnobiology • genetics •
- immunology • medicine • paleontology • toxicology • zoology • …

Applied science is the application of knowledge learned by the other sciences to develop new products and technologies. Additionally, new knowledge in other classifications may come during this development.

- agriculture • engineering • fire suppression • forensics • nuclear •
- pharmacy • programming • robotics • …

Social science is the study of behavior, culture, society, and the mind.

- anthropology • archaeology • criminology • law • linguistics •
- pedagogy • politics • psychology • sociology • …

Even with these new classifications, much scientific advancement still occurs across multiple classifications: interdisciplinary science.

- bioethics • bioinformatics • cognitive science • cybernetics •
- evolutionary psychology • environmental science • library science •
- neuroscience • …

... redacted in preview ...
4.3 Types of research

**Basic (fundamental) research** focuses on expanding societies understanding of the world. Phenomena are studied, and theories developed and tested to better explain the phenomena. Much of the formal, physical, and some social science research is *basic research*. Basic research is the foundation of all future applications and the basis for creating new knowledge.

**Applied (product-directed) research** applies basic research in the development of new products and/or technologies. The goal is a product or technology with specific properties and characteristics. Much of the life, applied, and some social science research is *applied research*.

Some examples of product-directed research include
- low-friction bearings that handle the extreme temperature fluctuations of satellites in orbit around the Earth
- plastics that do not fade or crack in hot car interiors exposed to solar UV radiation
- efficient processes for removing oil from contaminated soil
- electronic devices that can sense and respond to touch

An interesting and active branch of applied research is *fiction-inspired research*. Many products available today or in development were inspired by futuristic television shows and movies: cell phones, self-driving cars, self-flying planes, invisibility cloaks, holographic displays, tablet computers, and home-cleaning robots, to name a few.

A reality in today’s society is that more funding agencies exist that fund applied research compared to basic research. To address this, researchers that conduct basic research may also conduct or collaborate with
4.4 Research methods

*If I have seen further, it is by standing on the shoulders of giants.* — Isaac Newton

There is no single procedure for conducting research — no single *scientific method*. Rather, research begins and proceeds via the general framework shown in Figure 4.3. Figure 4.3 also shows that there is no beginning or end to research: research builds on work done previously, and publishing the results allows others to conduct further research.
More on the construction of a research question is given in section 4.7.

A research question leads to the formation of one or more hypotheses. A hypothesis is a logical and testable explanation of a phenomenon. Being testable, the hypothesis must predict the outcome of future research.

- If the predictions are correct, the hypothesis gains strength and credibility.
- If the predictions are incorrect, the hypothesis is rejected. 

The predict–test–update cycle continues to refine the hypothesis to more accurately explain the phenomenon and to establish the applicable range of the hypothesis. Once understanding is achieved, the results are published, which adds this information to the body of scientific knowledge for other scientists to evaluate, support, criticize, and build upon. Some hypotheses are given below.

Assuming that drivers want to be safe on the road, drivers will slow down in anticipation of the light turning red.

The colors in the sunset occur because the Earth’s atmosphere is acting as a prism.

Together, increasingly thick and dark clouds, falling temperatures, and high humidity suggest that precipitation is forthcoming.

A theory is a set of rigorously tested statements or principles that explain a phenomenon and can be used to make predictions about the phenomenon. Evolving from a hypothesis, a theory is accepted by the scientific community as a correct explanation of a phenomenon, but it can still be disproved. The transition of a hypothesis into a theory may take millennia. Established theories include

- the theory of evolution
- quantum theory

... redacted in preview ...
More succinctly: a law explains what occurs and a theory explains how and why something occurs.

In 1687, Newton published his law of universal gravitation. The law made predictions that were testable, and the predictions were proven correct through countless experiments over the centuries.

In 1915, Einstein published his theory of general relativity. The theory proposed a coupling of space and time (spacetime). Newton’s law and Einstein’s theory make the same correct predictions in many situations, but make different predictions in situations involving massive objects and long distances, like planets, solar systems, and galaxies. Experiments show that Einstein’s theory correctly predicts the results of these extreme experiments.

Both Newton’s law and Einstein’s theory are still used. Newton’s law calculations are simpler, and are still used for Earth-bound projects. Einstein’s theory must be used for astronomical research and satellite operations. The common GPS (global positioning system) requires general relativity calculations.

Hypothesis development

Every research project is guided by an underlying hypothesis. Many disciplines explicitly state the hypothesis in the research project. Some disciplines, notably the physical and applied sciences, often do not explicitly express the hypothesis because the hypothesis is perceived to be obvious, at least to the researchers. However, not expressing the hypothesis may confuse readers and students.

For a hypothesis to be accepted by the scientific community, it must be
Medicine: The experimental drug will be no better than existing drugs. (null variant)
Sociology: Worker satisfaction increases quality and productivity.
Pedagogy: In otherwise healthy students, their forehead temperature is a measure of mental activity.
Psychology: Youths involved in petty criminal activity are more likely to engage in serious and/or violent criminal activity as an adult.

Experiments and/or studies produce data that supports (or not) the hypothesis. The hypothesis can be modified to better explain the data, or it can be discarded and a new hypothesis proposed. For example, the psychology hypothesis above could evolve to be

Psychology: In youth, there is a bifurcation age that dictates whether punishment for petty criminal activity results in decreased or increased probability of serious and/or violent criminal activity as an adult.
(Further work could explore the different types of punishment or correlate to youth demographics, etc.)

Research methods
There are several common methods of conducting research. Scientists use these methods separately and in combination to understand the phenomena they are investigating. The nature of the research question and nature of data means that disciplines tend to have a few preferred research methods.

Theoretical research: theoretical models are developed to predict or explain the results of other research methods.

- Chemists develop theories of chemical bonding and intermolecular interactions.
- Mathematicians develop functions that are used by scientists.
- Physicists are developing a theory of everything to unite the known forces.

Theoretical research leads to quantitative predictions that can be tested by ...

... redacted in preview ...

Relative experiments (also comparisons) quantify the results in relation to other samples being analyzed.

Biologists testing the effect of vitamins and/or nutrients on animal health.
Drug companies test new drugs against a placebo.
Geologists analyze core samples to identify geological events.

When conducting experimental research, preliminary experiments may be conducted that identify qualitative trends (response range, dose-response relationships, other variables, error sources, etc.). This information guides the development of quantitative experiments that provide optimal data.

Modeling: physical, conceptual, and computer-based models are used to mimic natural systems. The models are then used to make predictions on the real or related systems.

Biochemists use computers to model protein receptor sites in order to understand the binding process and identify molecular entities that may bind to the receptor.
Ecologists model carbon and energy flow in forest ecosystems.
Engineers build a scale model of a bridge and test it under different conditions.
Environmental scientists model ocean currents to understand nutrient flow.
Geologists model a river to assess erosion with varying flowrates.
Organic chemists make heme analogues to study the iron:oxygen interaction.
The model of the atom is a conceptual model (that has changed over time).
Weather forecasters predict the weather and project storm paths.

Models lead to quantitative results. Many models directly produce quantitative results. Other models identify experiments that, if confirmed, provide quantitative information on the phenomenon.

Opinion-based research: subjects provide data based on their beliefs, opinions, preferences, and/or emotions through questionnaires, interviews, and focus groups.

... redacted in preview ...
**Observational research**: a phenomenon is observed (studied) without interference from the scientist. *Correlational research*, where two or more variables are studied without any variables being controlled, is a form of observational research.

Biologists examine effects of logging and agriculture on bird populations.
An economist conducts a case study of the factors leading to a recession.
Darwin observed variability in finch species on the Galapagos Islands.
Early astronomers monitored the movement of the sun, moon, and stars, which led

... redacted in preview ...

<table>
<thead>
<tr>
<th>strongly disagree</th>
<th>disagree</th>
<th>neutral</th>
<th>agree</th>
<th>strongly agree</th>
<th>n/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>rarely/never</td>
<td>seldom</td>
<td>regularly</td>
<td>often</td>
<td>almost always</td>
<td>n/a</td>
</tr>
<tr>
<td>much lower</td>
<td>lower</td>
<td>equal</td>
<td>higher</td>
<td>much higher</td>
<td>n/a</td>
</tr>
<tr>
<td>very dissatisfied</td>
<td>dissatisfied</td>
<td>neutral</td>
<td>satisfied</td>
<td>very satisfied</td>
<td>n/a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>does not apply</th>
<th>applies a little</th>
<th>applies somewhat</th>
<th>applies a lot</th>
<th>very much applies</th>
</tr>
</thead>
<tbody>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**Figure 4.4** Common questionnaire scales. Depending on the questionnaire, ‘not applicable’ (n/a) may not be included as an option.
Observational research is commonly used in the social sciences to study a group without affecting the group behavior or when imposing constraints on parts of the group would be unethical. In some cases, observational studies provide a foundation for quantitative studies. For example, physicians observed higher cancer rates in people living close to high voltage power lines. Statistical analysis of the data has confirmed this, and theoretical, experimental, and modeling research into a cause is ongoing.

Tests on patients with clinical depression showed that they have
- increased neuron receptors for serotonin and norepinephrine
- decreased levels of serotonin and norepinephrine

However, the cause-effect relationship between these three observations is uncertain. Does depression increase the number of receptors and deplete neurotransmitter levels? Does a build-up of receptors deplete neurotransmitter levels and cause depression? Does a depletion in neurotransmitters (by a yet unknown cause) both increase the receptor levels and cause depression?

These observations are correlated because there is no understanding of the cause-effect relationship. Further experimental research could determine this relationship.

**Data mining:** data initially collected for one purpose is analyzed for another purpose.

Analyzing accident rates before and after changes to traffic flow at an intersection.
Analyzing medical records to investigate the origin and transmission of an illness.

Another definition of data mining involves the extraction of information from large data sets. This type of data mining may require large computers and artificial intelligence software to extract and analyze the
research. Observational research often leads to quantitative research projects and contributes to the formation of new hypotheses. Theoretical research provides mathematical and logical foundations that support and provide broader understanding of other studies and experiments.

The following story illustrates the use of different research methods to prove a suspicion in the face of strong corporate opposition.

In the late 1940s, physicians observed that smokers had an increased rate of lung cancer. Observational studies mined existing medical data to confirm that patients who smoked had a higher rate of lung cancer compared to non-smokers. Cigarette companies criticized these studies. Researchers realized that a quantitative dose-response study was needed to confirm the relationship. It would be unethical to conduct an experiment that forced randomized groups of people to smoke different amounts. A challenge was to design a study that quantified the amount of smoke animals were exposed to. In the mid-1950s, Ernest Wynder and colleagues had an ingenious idea: they condensed the chemicals from cigarette smoke into a liquid and applied this to the skin of groups of mice. Above 6 g/yr, a statistically significant percentage of the groups developed cancer. Wynder also shows that mice with the highest doses had an average 23% shorter lifespan.
Method validity

There are several types of validity, and you must be able to answer the question — “Is your experiment/study valid?” — for all types. The applicability of each type of validity depends on the area of science and the nature of the experiment/study.

*Construct validity* pertains to confirming that the experiment/study is actually measuring what is proposed. For example, is the scientific instrument measuring the expected entity? Are there interferences that are artificially enhancing or blocking the signal? Do survey results accurately translate to the emotional state of the participant? Is the operationalization of the data valid?

†Statistical validity pertains to the analysis of your numeric data and drawing conclusions as to the relationship, if any, between the variables. Section 2.7 presents a simple statistical analysis of a data set.

Internal validity pertains to the cause-effect relationship of the data. Did A cause B, or did B cause A? Or did another factor affect B that caused A? For example, if the same students completed both the pretest and posttest, it is possible the difference was due to the students having awareness of the types of questions on the assessment (or the actual questions, if the same test was used).

If you cannot prove internal validity, you have conducted an observational (correlational) study.

External validity assesses whether the results can be generalized to related groups. It is a reflection of how representative the sample is of the general population. Can a drug study on adults be generalized to children? Is a study affected by cultural norms? Do water samples...

... redacted in preview ...
4.5 Academic integrity and research ethics

*Academic integrity* refers to a moral and ethical code of conduct that demands high academic standards, academic rigor, honesty in learning and research, honesty in the works you produce, and requires that you expect this code of conduct from others. All academic institutions have an academic integrity policy, and all academic staff must have a research philosophy that avoids academic misconduct:

- fabrication/falsification of data
- unethical treatment of subjects
- exclusion of data
- plagiarism
- fraud
- bias

Misconduct concerns all scientists because, when one scientist does it, it draws into question the impartiality of all scientists and all published scientific work. Scientists should continually monitor themselves and their colleagues for possible lapses in conduct. As a scientist, you are responsible for ensuring your work is done correctly, that results are accurate, and that conclusions are reasonable. However, some scientists do engage in unethical practices. Some reasons for this are listed below.

- Research funding is getting more challenging to obtain, so there is pressure to embellish and exaggerate results to get funding.
- Funding sources with a stake in the results of the research, such as pharmaceutical and for-profit corporations, threaten to withdraw funding if the companies’ preferred results are not obtained.
- Scientists desiring prestige and recognition may embellish results.

... redacted in preview ...
are a permanent record of what they did. Other researchers may endeavor to repeat the research, and question the original researcher’s claims if they obtain different results. Additionally, automated search and compare tools are becoming increasingly sophisticated. Copying something from an obscure book will eventually be discovered, and one such event can draw into question a researcher’s entire research record.

**Code of research ethics**

*Honesty*: strive for honesty in all scientific communications. Honestly report data, results, methods and procedures, and publication status. Do not fabricate, falsify, or misrepresent data. Do not try to deceive colleagues, granting agencies, or the public.

*Objectivity*: strive to avoid bias in experimental design, data analysis, data interpretation, peer review, personnel decisions, grant writing, expert testimony, and other aspects of research where objectivity is expected or required. Disclose personal or financial interests that may affect research.

*Integrity*: keep your promises and agreements, act with sincerity, and strive for consistency of thought and action.

*Carefulness*: avoid careless errors and negligence; carefully and diligently examine your own work and the work of your peers. Keep good records of research activities, such as data collection, research design, and correspondence with agencies or journals.

*Openness*: share data, results, ideas, tools, and resources. Be open to discussion, criticism, and new ideas.

*Respect for intellectual property*: honor patents, copyrights, and other forms of intellectual property. Do not use unpublished data, methods, or... redacted in preview...
**Responsible mentoring**: help to educate, mentor, and advise students. Promote their welfare and allow them to make their own decisions.

**Respect for colleagues**: respect your colleagues and treat them fairly.

**Social responsibility**: strive to promote social good and prevent or mitigate social harms through research, public education, and advocacy.

**Non-discrimination**: avoid discrimination against colleagues or students on the basis of sex, race, ethnicity, or other factors that are not related to their scientific competence and integrity.

**Competence**: maintain and improve your own professional competence and expertise through lifelong education and learning; take steps to promote competence in science as a whole.

**Legality**: know and obey relevant laws and institutional and governmental policies.

**Animal care**: show proper respect and care for animals when using them in research. Do not conduct unnecessary or poorly designed animal experiments.

**Human subjects’ protection**: when conducting research on human subjects, minimize harms and risks and maximize benefits; respect human dignity, privacy, and autonomy; take special precautions with vulnerable populations; and strive to distribute the benefits and burdens of research fairly.

Before conducting research involving humans or animals, you will need approval from an Institutional Review Board (also called the Research Ethics Board, Ethical Review Board, or Independent Ethics Committee). The Board provides an independent assessment...
4.6 Conducting an investigative project

Investigative projects consolidate and summarize existing knowledge. They are common in business and academia. Examples include:

- A business plan containing a summary of what other businesses are doing as they make a case that their business will succeed.
- A business preparing a document consolidating their products for their shareholders or for potential investors.
- A student preparing an academic essay as part of a course.
- A person joining a research group preparing a review summarizing the research in the field and uses this to decide on their research project.
- A seasoned researcher preparing a review article of the area he has been studying for several decades.

Steps for conducting an investigative project

The steps for conducting an investigative project are given below:

1. formulate an investigative question
2. conduct a literature review and analysis
3. prepare document(s) and presentation(s)

These steps occur concurrently! Figure 4.5 shows that the early focus is on the literature review and analysis and the later focus is on document and presentation preparation, but there is significant overlap. As your project progresses, you continue to consult the literature and incorporate this information into your developing documents. Writing begins early and continues through the entire project. (Writing does not start in the last days before, or the night before, the document/presentation is due.)
4.6 Conducting an investigative project

Timeline: <descriptive investigative project title>

<table>
<thead>
<tr>
<th>Literature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>review</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Work preparation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>report (essay)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>status updates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>review process</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4.5**  A sample timeline of the activities a person completing an investigative project will conduct. The thickness of the activity bar illustrates the amount of time spent on that aspect of activity. This project requires the person give regular status updates to their supervisor. The final document is an essay on the project.

**Overview of steps**

*Formulate the investigative question:* the investigative question clearly defines the objectives of the investigation: what are you trying to understand? The question must be clear, concise, coherent, and precise. While conducting the literature review, you may discover that your question is already answered or too broad given the available time. In these cases, the investigative question must be modified and focused.

*Literature review:* learning what is known about the field. The literature review is the major component of an investigative project. You are expected to identify all the significant contributions to the field.

*Literature analysis:* analyzing the information to understand how this ... redacted in preview ...
4.7 Conducting a research project

Don’t dive into unknown waters. — sage advice to prevent injury and death

Choosing to conduct a research project is the same as diving head-first into unknown waters. Consider:

- Research is an investigation of the unknown.
- There are no ‘correct answers’ to compare your results to.
- There is no-one telling you what to do.
- Failure is common, but not a cause for punishment.
- There are people (other researchers, people with different beliefs) ready to criticize and attempt to discredit your work.

So why engage in research? For the challenge. For the fun. To be the first to know something new. To benefit science and society. And critically: because you have a passion for research.

Researchers engage in research to challenge and extend their intellectual capabilities.

Athletes engage in sport to challenge and extend their physical capabilities.

Fortunately, people learn how to conduct a research project, as illustrated in Figure 3.8. Undergraduate and graduate courses provide you with the background knowledge and a foundation to design research projects. Laboratory courses provide you with skills that you will use and build upon when conducting research. Initially, you will conduct research under the supervision of a principal investigator (professor) as an undergraduate and then graduate researcher. Their mentorship should hone your knowledge, laboratory skills, research skills, and builds your
Steps for conducting a research project

The steps for conducting a research project are given below:
1. formulate a research question and hypotheses
2. conduct research to test the hypotheses
3. prepare document(s) and presentation(s)

Step 1 must be complete prior to conducting experiments and/or studies. Once complete, steps 2 and 3 proceed concurrently throughout the project. Figure 4.6 shows that the early focus is on conducting research and the later focus is on document and presentation preparation.

As a guide, expect to spend
• 20% of your time reviewing and analyzing the literature
• 60% of your time engaged in research
• 20% of your time preparing works

Timeline: <descriptive research project title>

<table>
<thead>
<tr>
<th>week:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature review</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data collection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A - design &amp; set up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A - conduct study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B - design &amp; set up</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B - conduct study</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

... redacted in preview ...
Overview of steps

**Formulate the research question.** This step involves an extensive literature review and analysis to develop a focused research question.

**Literature review and analysis.** Regular review of the literature can provide you with new information and new methods to aid your research.

**Hypothesis development:** with an understanding of what is known in this field, you refine or propose an explanation — a hypothesis — for the phenomenon.

**Research method design:** methods are proposed to test the hypothesis. These methods are often variants of those found in the literature. Before beginning full-scale research, a pilot study/experiment may be conducted to ensure the method yields the desired data. Method refinements improve the quality of the data. The resulting method is documented in sufficient detail so that others scientists are able to reproduce it.

**Data collection:** data is collected. Observations are recorded to understand and aid in the data analysis.

**Data analysis:** the data is analyzed and conclusions are made regarding the correctness of the hypothesis. Additionally, an objective meta-analysis of the research method design, data collection, and data analysis is conducted. You *do not* want to publish erroneous results and conclusions.

The above steps are repeated until you have a comprehensive understanding of the phenomenon, are able to answer your research question, and understand how this new knowledge affects the scientific

... redacted in preview ...
4.8 Research question development

Extensive thought, planning, and preparation are required before beginning a research project — before delving into the *unknown*. These tasks include

- creating a focused research question
- identifying the goals of the research
- conducting an extensive literature search
- identifying the data required to answer the question
- identifying strategies to extract the most information from that data
- identifying research methods to collect the data
- obtaining permissions and funding to conduct the research

This planning and preparation is not linear, as illustrated in Figure 4.7. For example: while conducting the literature review, you may discover that your research question is already partially answered, too broad given the available time, and/or that the necessary resources are not available. In these cases, the research question must be modified.
The research question is a clear, concise, coherent, and precise question to be answered via scientific research. A good research question must be feasible, interesting, novel, ethical, and relevant. It must lead to the formation of one or more testable hypotheses that provide data to answer the question. A thesis statement is equivalent to a research question, just not in the form of a question.

The object of education is to leave a person in the condition of continually asking questions. — Bishop Creighton

You need to create a research question that interests you because you will be conducting this research for months or years. While extensive planning goes into the development of a research question, it may need to be modified if anomalous results, new literature information, equipment problems, and/or other unforeseen events are encountered. This is the nature of research!

There are different levels of research question. Principle investigators (professors) have a broad research question that may guide their research for decades. Graduate and undergraduate students working for that PI may either select a research question proposed by the PI or propose a focused research question within the scope of the PI’s research question.

- What factors affect the synthesis and construction of commercially viable organic light emitting diodes? (broad research question)
- How does R-group electronegativity affect quantum yield? (student project)
- What environmental factors degrade LED performance, ...

... redacted in preview ...
4.8 Research question development

**goals**
- Why is the research being conducted?
- Who will benefit from the results?

**literature**
- What is currently known about this topic?
- What does theory predict for results?
- How will this research improve the current theories?

**methods**
- How have others conducted similar research?
- What research methods can you use to conduct the research?
- What improvements can you make to the existing research methods?

**data**
- What data is required?
- How will the data be analyzed?
- Is the data consistent with theory?
- Are there other plausible interpretations of the data?

**permissions**
- Is ethics approval required?
- Do you need permission from governments, law enforcement, companies, or landowners?
- Do you need to schedule satellite time, ship time, etc?

**funding**
- How much money is required?
- Who might fund this research?
- What is/are the application process(es) and timeline(s)?
- What happens if you do not get all the funding you expect?

... redacted in preview ...
4.9 Literature review and analysis

It is important to determine what is already known about your topic so you can build on the work done by others. Scholarly articles (often called papers or primary literature) are the primary means of publishing new scientific information. Scholarly books, such as textbooks and theses, present greater explanations of complex theories than is reported in scholarly articles. However, scholarly books typically undergo less peer review than scholarly articles.

![Diagram of increasing technical level and rigor in peer review]

Figure 4.8 Common publications that have some degree of peer review.

When conducting a literature review, you should endeavor to use scholarly articles and scholarly books. These resources provide the best impartial knowledge on your topic. One type of scholarly article is a review article, which reviews and summarizes the research and current understanding of a scientific field. Recent review articles provide an excellent overview of the field and provide references to more focused scholarly articles that may be relevant to your project.

... redacted in preview ...
Literature resources

There are many resources available for you to conduct a literature review. A common way to begin is to conduct a literature search of one or more databases.

• University libraries have access to databases that index more rigorous publications (conference proceedings, scholarly books, and scholarly articles).
• Schools and public libraries have access to databases that index less rigorous publications (newspapers, science magazines).
• Internet search engines often link to scholarly articles.

The resources available to you vary depending on your institution. The best advice is to talk to a librarian, who can direct you to the most appropriate resources for your project.

Scientific databases index the titles and abstracts of articles from specific disciplines (science, medicine, social science, etc.). Common scientific databases include SciFinder, ScienceDirect, MedLine, and Web of Science. Google Scholar is a free database available at http://scholar.google.com

Once you find an article, most databases link to both the articles cited and the articles that cite the article you found. This allows you to identify the articles that introduce each aspect of the research and identify the articles that present the latest understanding of these aspects.

**Effective use of search engines**

All search engines have numerous advanced abilities:

• searching for specific phrases
• including and excluding words and phrases

... redacted in preview ...
Assessing credibility

Internet search engines link to scholarly books and articles, but also link to personal and commercial websites. You should always be wary of bias when reading personal and commercial websites. Bias is often encountered when investigating controversial topics (abortion, environment, GMOs, religion, politics, …) and commercial topics (fitness, health, technology, …).

A word on Wikipedia: in general, Wikipedia is a good and readily accessible resource. But because anyone can create and edit an article, and these are not reviewed before becoming accessible to all. Consequently, Wikipedia is subject to bias and misinformation. Controversial topics side with popular beliefs at the expense of factual information." For these reasons, Wikipedia articles should be used with caution and the information confirmed in scholarly articles. The references in Wikipedia articles often link to scholarly articles. These links can also be used to judge the neutrality of the Wikipedia article itself.

Peripheral information

As you conduct the literature review and research, you will learn about related topics. This peripheral knowledge adds to your understanding of the field and how it affects society, and may be valuable when you answer questions on your work. However, peripheral knowledge is not included in your focused scientific work. First drafts commonly contain irrelevant and superfluous information that must be removed through the review process. However, what is considered relevant to a given project depends on the author, reviewers, and readers.

... redacted in preview ...
4.10 The realities of research

The most exciting phrase to hear in science, the one that heralds new discoveries, is not “Eureka!” but “That’s funny.” — Isaac Asimov

Research is incremental

Research incrementally advances our understanding. Profound discoveries are rare. Often, it is a serendipitous observation or realization, and an open mind by the researcher, that results in a profound discovery. Common research projects include

• applying known chemical reactions to produce a new entity
• expanding an existing model to incorporate additional parameters
• integrating new or different components together to produce a new product

In 1957, the British Antarctic Survey began ground-based recordings of stratospheric ozone levels in Antarctica to better understand the role of atmospheric ozone. They observed seasonal fluctuations that they attributed to natural fluctuations. However, starting in the mid 1970s, the fluctuations became increasingly extreme. By the 1980s, the summer ozone levels over Antarctica were near zero (the “ozone hole”).

In the 1960s, James Lovelock designed instruments to detect and quantify trace gases in the atmosphere. One instrument was sensitive to chlorofluorocarbons (CFCs), which were used as refrigerants and aerosol propellants. Lovelock observed that CFCs were stable and non-reactive. He proposed using CFCs to trace atmospheric airflow.

... redacted in preview ...
In 1995, Rowland, Molina, and Crutzen shared the Nobel Prize in chemistry for their work.
(Source: adapted from The Practice of Science: An Introduction to Research Methods, by Anthony Carpi and Anne Egger. Used with permission.)

In this story, no one researcher set out to discover ozone depletion. Individual researchers conducted studies that formed a web of knowledge that led to many interesting and unexpected discoveries, such as the link between CFCs and ozone depletion, and the link between ozone depletion and skin cancer. The entirety of the research involved many research methods to create a coherent story about the role of ozone to life, and how humanity affects and is affected by it.

**Research is collaborative and competitive**

Unlike undergraduate laboratory experiments, research is not done alone. A research professor will have a research group consisting of post-doctoral research associates, graduate students, and undergraduate students that conduct research under the professor’s direction. The composition and size of the research group will depend on the professor’s funding and the institution.

Within the research group, you will have “your” project. However, you have your laboratory colleagues, the research associates, and the research professor to talk to about your project. You share ideas, assist each other with studies/experiments, teach each other how to do certain procedures, and generally learn from each other. But you are responsible for conducting the research on your project.

Your professor may collaborate with other professors conducting similar...  
... redacted in preview ...
Like collaboration, competition also occurs. Positively, this serves to challenge the researchers and speeds up research. Negatively, this may lead to animosity and lost collaborations.

**Research explores the unknown**

*Uncertainty is common in research.* After completing a step, you must decide what to do next, with several pathways to choose from. Each pathway has benefits and drawbacks:

- *is it reasonable?* (Does it have a reasonable chance of success?)
- *is it possible?* (Have other research groups done similar work successfully?)
- *is it beneficial?* (Will we be in a better position if successful?)
- *experience of personnel* (Do we know how to do it?)
- *availability of equipment and resources* (Do we have what is needed?)
- *cost* (Do we have sufficient funds to complete it?)
- *safety* (What are the risks? How can they be mitigated?)
- *time* (How long will it take? Do we have sufficient time?)

For most pathways, one or more of the above points will not be in your favor. You and your research group must decide which path to follow.

---

**Lost in a forest**

Being lost in a forest is a good analogy of the research process. You are lost on a trail in the woods. When you come to a junction, you must choose which trail to follow. There could be many trails to choose from. You can see a little down each trail, and must pick one based on some factor (how much use it has, the direction it appears to be going, how easy it is to traverse). Trails could lead to other junctions, dead ends, back to where you already were, or to... (redacted in preview...)}
While you can see the entire trail system here, you will never see all the pathways when conducting research. Once you have a working pathway to your desired results, there is little reason to go back and try the ideas you previously rejected.

**Undergraduate laboratory courses**

As you proceed through high school and university, you attend laboratory classes where you start and complete an experiment in one to four hours. The experiment you conducted reproduces a known, previously published, experiment. Within a week, you analyze the data and submit a report. You may lose marks if the experiment does not work or if your results are not close to the “correct” value.

*This is not research!*

First, research is an investigation of the unknown: there are no correct answers to compare your results to. Second, research takes weeks to ... redacted in preview ...
science courses, the laboratory experiments should become increasingly like “real” research in that you may be required to conduct a literature review and develop a procedure, and the experiment may take several laboratory periods to complete. In some experiments, you may analyze systems for which the answer is not known.

The entire laboratory program — from high school to fourth-year science courses — prepares you to conduct research.

Additional resources …

... on the history of science

... on research methods

... redacted in preview ...
Chapter 5. Documents and presentations

In your career, you will do many of the following:

• document the work you are doing
• discuss your work with colleagues and collaborators
• write memos to your supervisor and to the people you supervise
• apply for project approval and/or funding
• present your work to coworkers and at conferences
• prepare instructions for others to follow
• prepare reports for clients
• prepare articles for journals and magazines
• write press releases

In all cases, clarity, coherence, concision, and precision are of the utmost importance. You must communicate information in a manner the reader understands and expects. Figure 5.1 illustrates the usual audience of different public and scientific documents.

---

<table>
<thead>
<tr>
<th>Increasing technical information</th>
</tr>
</thead>
<tbody>
<tr>
<td>newspaper</td>
</tr>
<tr>
<td>internet</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

---

little scientific knowledge  X  AUDIENCE  X  expert in the discipline

... redacted in preview ...
Figure 5.2 illustrates the similarities between an academic work and a literary work.

![Diagram showing the structure of academic and literary works]

**Figure 5.2** The similarity in structure of a scientific document and dramatic story.

Literary works and academic works have several similarities:

- Both tell a coherent story.
- The introduction foreshadows the results and conclusions.
- There should not be any irrelevant information.

For example, consider the television show *CSI (Crime Scene Investigation)*, which bridges the literary and academic realms. The incriminating evidence is presented clearly and logically so that the viewer can understand how the conclusions were reached. You must do this with your data.

... redacted in preview ...
5.1 Document and presentation development

How many discoveries go unreported?

*Communicating the results of your research/investigative project to others is the most important aspect of every project.*

If your results are not published, they do not advance society’s knowledge and no one is able to build upon that knowledge. All results should be published, including those that do not confirm your hypothesis. This information is useful to other researchers.

Whatever documents and presentations you prepare, they must focus on answering the research/investigative question you proposed. That said, you may have collected data that also answers other questions. It is possible that you can propose additional questions and already have the data to partially answer those questions in future documents and presentations. This is the nature of research!

*The important thing is never to stop questioning.* — Albert Einstein

All of your work is documented in your notebook. You should also write a summary of each study/experiment you conduct in your notebook. These summaries must be comprehensive of the work you have done as they form the basis for the documents and presentations you prepare based on that work. The summaries need not be submission-quality, but they must be comprehensive with regards to the study/experiment and comprehensible so you can prepare quality documents and presentations.

*literature review*

... redacted in preview ...
Figure 5.3 The preparation phase involves several development cycles before progressing to the revision phase, which again involves several cycles to prepare a quality document/presentation.

**Document preparation** begins when you begin the literature review. Begin drafting your document(s) by organizing your notes into paragraphs and sections. As you collect data and/or read additional resources, review and revise your developing document(s). Regular review of your developing document(s) reminds you of the overall

... redacted in preview ...
new, novel, and/or controversial topics. Readers — scientists, politicians, corporations, and the public — may question your data, your analysis, and your neutrality. Scientists critically evaluate the work of others. You should evaluate your own work to the same or higher standard that you evaluate the work of others. Furthermore, not everyone is open-minded and accepting of alternative perspectives. Some may want to discredit your research/investigation because it does not agree with their beliefs. Your discussion and conclusions must be supported by your data and convincingly argued. You should also acknowledge limitations in your data and acknowledge competing interpretations, and then explain why your interpretation is most appropriate.

Remember that inductive results cannot conclude or prove anything. Inductive results may support the hypothesis, but there may be other valid interpretations. Indeed, science continually develops better models that explain both the historical data and the anomalies that early models could not explain.

Once you have completed the project and written the first complete draft, read the document in its entirety and revise it to ensure there is a logical and coherent train of thought. Do not be surprised if your first revision is a substantial rewrite. The goals of this self-review are to

• remove redundant and extraneous information
• move information to more appropriate locations
• clarify confusing sentences and paragraphs
• adjust the language and terminology to the appropriate level

Strategies for self-review include:

• Read your work aloud. This allows you to simultaneously read and hear the logical progression in your prose. Recall that you should be
• If you find yourself referring to other parts of the document, revise the section to bring the relevant information to the required location.

• If you find yourself rereading a sentence/paragraph to understand it, it must be revised. Common causes include overly complex sentences, poor grammar, misplaced modifiers, poor linkage of old and new information, and paragraphs that contain more than one concept.

• Ensure that every sentence and every paragraph conveys information, that excess words are removed, and that repetition is minimized. (This being the focus of Chapters 1, 2, 5, and 6 of Communicating Science!)

Put simply, if you do not understand what you have written, your reader does not have a chance. They will get frustrated and give up reading your work. Recall that you are striving for a clear, coherent, concise, and precise document.

Wait a few hours to a few days (depending on the document length) before repeating your review. This delay makes you more objective. You may be surprised that what made sense when you prepared the work does not make sense when you review it. Repeat this self-review until you believe there is a logical and coherent train of thought in the work. Once you believe you have a reasonable work, external revision begins.

Revision involves giving your beloved work to colleagues and asking them to pick it apart. Their job is to identify grammatical errors, information that is redundant and irrelevant, and sections that do not flow. Put your work aside until you receive the external feedback, then review it again yourself.

If a work requires significant revision, the reviewer may substantially reformat sections and/or write large amounts of material for inclusion in the work. The acceptability of this depends on the environment.

... redacted in preview ...
The difference between the *independent* student academic environments and *collaborative* professional and employment environments is simple to explain. Students must learn how to independently prepare documents so that they can effectively contribute to team documents. Preparing scientific documents develops their ability to identify and evaluate relevant works, to synthesize new knowledge from research and place it in the context of existing knowledge, and to communicate this knowledge to others. Professionals have these skills, and the focus is on preparing the best document for the client.

The nature of your project dictates how long you spend preparing and revising it. At least one other person should review a laboratory report. A research article will be reviewed by your colleagues (more than once), by your supervisor (more than once), and by two to five anonymous reviewers chosen by the journal editor.

As a graduate student, I was asked to watch a fellow student’s rehearsal for their defense. They gave a good presentation, but I commented that their presentation contained too many images of the research setting (mountain ranges and pollution source) and not enough on the science (methods, analysis, and results). The student and their friends instantly spurned me for “criticizing” the presentation. The student gave the same presentation at their defense, and the committee was also concerned by the lack of science in the presentation. The student was required to expand these sections before the thesis was approved.

The moral of this story is that, if you ask someone to review your work, they have given you their time, and you should consider their comments rationally. (Chapter 6 provides more information on the review process.)
Document formatting: general guidelines

Most scholarly documents have minimal formatting, and the following configuration will work for them. Once configured, save it as a document template and use it for all the scholarly documents you prepare. (Appendix B.1 provides instructions for configuring your page layout, text styles, and creating templates.)

Page layout
- 2.5 cm margins on all sides
- 1.0 cm gutter margin if the document is stapled or bound
- If your document is double sided, mirror the margins
- header: 2.0 cm from edge; footer: 1.8 cm from edge

Text styles
- Use a minimum number of fonts: one font for the title and headings, another font (or the same font) for the text.
- 1.0 or 1.5 spacing (1.0 is single spaced)
- headings
  - maximum of two heading levels for most documents
  - a single font for all headings levels (Arial or Times New Roman are common)
  - adjust the font size, font formatting, and space before/after to create white space between sections
- lists, equations, examples: all are indented from the surrounding text
- references are formatted in the style required by the instructor, employer, or publisher

The following text styles will give your documents a simple, logical... redacted in preview...
The Spacing:Before and Spacing:After settings create white space between the objects (text, figures, tables) on the page. White space is important because it identifies what objects go together conceptually. Too little white space makes the page cluttered and difficult to read.

For example, consider headings: the large space before the heading creates a visual break between the sections, and the small space after the heading links the heading to the following text.

**Document improvement: spelling and grammar analysis**

Word processors can analyze your document for both spelling and grammar, and recommend changes to improve both. Repeat this analysis regularly as you prepare your document, but do not automatically accept the recommendations. While most recommendations are beneficial, the word processor is not programmed with all scientific terms and proper nouns, and sometimes interprets scientific phrases incorrectly. Critically review all recommendations to determine if the suggestion retains the same meaning and improves the clarity, cohesion, concision, and precision of your work.

**Document improvement: document readability**

Word processors can calculate the readability of a document. Numerous factors affect the readability, including average word length and average sentence length. The underlying premise of readability analyses is that shorter words and shorter sentences are easier to comprehend.

Word processors often calculate the Flesch-Kincaid readability statistics.* Two statistics are reported:

- **Reading ease**: the higher the reading ease, the easier the document is
Table 5.1  Recommended readability statistics for scientific and public documents. The correlation between reading ease and grade level is approximate.

<table>
<thead>
<tr>
<th>Document</th>
<th>Reading ease</th>
<th>Grade level</th>
</tr>
</thead>
<tbody>
<tr>
<td>graduate documents; scholarly articles</td>
<td>&lt; 30</td>
<td>&gt; 14</td>
</tr>
<tr>
<td>undergraduate documents</td>
<td>30 – 40</td>
<td>12 – 14</td>
</tr>
<tr>
<td>popular science articles; technical reports</td>
<td>30 – 50</td>
<td>10 – 14</td>
</tr>
<tr>
<td>general audience (newspapers, websites)</td>
<td>50 – 70</td>
<td>6 – 10</td>
</tr>
<tr>
<td>children’s books</td>
<td>&gt; 70</td>
<td>&lt; 6</td>
</tr>
<tr>
<td>Communicating Science</td>
<td>47</td>
<td>10</td>
</tr>
</tbody>
</table>

Section B.1 shows how to calculate the readability statistics for your document.
5.2 Notebooks

Many careers require the keeping of a notebook: science, journalism, law enforcement, etc. Notebooks are valuable for both research and investigative projects. The notebook is a repository of all the information you have collected on a project, recorded when you obtain the information. The laboratory notebook is a permanent record of what you did and what you observed, written while you conducted experiments. This allows you to accurately document materials, procedure, modifications, and observations, and to show your timeline for completing the work.

The information in your notebook forms the basis for every document and presentation you prepare on the project.

The research notebook is a legal document in patent cases. The information in a notebook is critical to confirming when and how a discovery or an invention occurred. Errors in maintaining a notebook can seriously damage a discovery claim or patent application, and may void an existing patent.

Electronic laboratory notebooks are a recent technological development that is gaining acceptance in academic and industry. The software is

... redacted in preview ...


Project: **Using a laboratory notebook**

The notebook

- Use bound notebooks with numbered pages.
- Number notebook volumes sequentially and with the start and end-use dates.
- Use NCR (non-carbon recording) paper or have a policy of photocopying pages once they are complete. At pre-determined times (end of day, end of week, end of experiment), submit copies to the laboratory supervisor for review and off-site storage. In the event of an accident, having an off-site copy is critical to continuing from where you left off.
- Do not add or remove pages. Adding or removing pages destroys the credibility of all the information in the notebook.
- Keep lab notebooks in a safe place when not in use.
- Keep lab notebooks for at least 20 years after completion.

Notebook organization

- Reserve the first four pages for a table of contents. Add an entry to the table of contents every time you start a new experiment.
- Complete the notebook chronologically. Do not leave space to complete a project. If you are working on multiple projects, draw a dividing line each time you switch projects.

Legal considerations

- Write legibly! It must be possible for you and others to understand what you have written and to reproduce your work.
- Write information directly into your laboratory notebook. Copying information...

... redacted in preview ...
Legal considerations (continued)

• If something doesn’t work, don’t write dismissive statements in the notebook. Legally, it can be argued that you abandoned the idea.
• Use permanent ink that does not bleed. Most inks are stable in water, but many inks bleed in common laboratory solvents, as shown below.

<table>
<thead>
<tr>
<th>Pen</th>
<th>Control</th>
<th>Erase</th>
<th>Water</th>
<th>Methanol</th>
<th>Ethanol</th>
<th>Acetone</th>
<th>Baked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bic Accountant fine point (red)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Bic Accountant fine pt (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Bic Round Stic med (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Cross fountain pen (blue/black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Dixon Ticonderoga 19082 soft pencil</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Pentel Hybrid Gel Roller (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Pilot G-2 07 (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Gelly Roll fine (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Gelly Roll fine (blue)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Gelly Roll XPG (blue)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Gelly Roll XPG (green)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Gelly Roll XPG (red)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sakura Pigma Micron 45 mm (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Sharpie extra fine (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Sharpie extra fine point (red)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Sharpie ultra fine point (blue)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Uni-Ball Gel RT Med (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Uni-Ball Vision fine (black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Uni-Ball Vision fine (blue)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Sanford Uni-Ball RT fine (blue)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>Zebra Sarasa 0.7 (blue/black)</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
<td>12.3</td>
</tr>
</tbody>
</table>

... redacted in preview ...
Project: Using a laboratory notebook

Documenting projects

• When starting a project, give a brief overview of the project, including the relevant theory and rationale behind the project.
• Include a flow chart of the project and detailed flow charts of each experiment.
• List the reagents (including manufacturer and lot number), organisms (supplier, line history, delivery conditions, storage conditions), and equipment used (make and model number).
• List the experimental setup, plus any notes or references to why you selected this experimental setup.
• Detail the experimental procedure or reference a published procedure.
• Detail tweaks made to the procedure during the experiment.
• If something must be inserted, such as a picture, permanently affix it to the notebook and have its placement witnessed by another person.
• Date and sign every page and have your laboratory supervisor sign each page. The laboratory supervisor should not be directly involved in the project.

Information that should be recorded

• Record everything when it is measured or observed.
• Record experimental details: equipment settings, temperature, pressure, flow rates, light levels, environmental conditions, etc., and how they changed during the experiment.
• Record experimental data (it is often convenient to tabulate data).
• If data are collected electronically, record the filename in the notebook.
• Record observations made during data collection. Anomalous observations... redacted in preview ...
5.3 Storyboarding

It is all-too-common for people to sit down in front of a computer or with a pad of paper and have their mind go blank. They know the goal is to answer the research/investigative question and they have a good understanding of the information and what needs to be conveyed, but the big questions are “Where do I start?”, “What do I say?”, and “How do I say it?” Much of this hesitation comes from having too much information, from not knowing what information must be conveyed, from having too long a document to prepare, and from believing they are writing the finished document. For you to avoid and overcome these barriers,

- **start early**: by distributing the writing process throughout the project timeline, you are not overwhelmed by the volume of information you have or the volume of writing you must do.
- **realize you are not writing the finished document**: once you accept that what you write does not need to be perfect — that it will require review and revision — it is easier to write material that will eventually transform into the finished document.
- **prewrite**: prewriting is the process of collecting and organizing information to establish the structure and content of your document.

Prewriting

There are many methods of collecting and organizing information. Below are some common prewriting strategies. You may find that you use all of these strategies at different times, but that one generates the most information and smoothly leads to the draft document.

- **Brainstorming**: writing the ideas and information that is relevant to the... redacted in preview...
• **Questioning**: consider the project as a news story and ask questions about the project. Strive to answer the questions *who, what, where, when, why, and how* about the project. These questions may identify better questions. The answers form the draft document.

• **Storyboarding** (also **outlining, mapping**): a more structured version of brainstorming where the information is organized directly into sections. Each section is developed independently of the others, and the combined sections forms the draft document.

You need to try different methods and find a method that works for you.

**Storyboarding**

Storyboarding is commonly used when preparing scientific documents and presentations. Storyboarding works well with the established common structure in scientific documents: *Introduction, Methods, Results, Discussion, Conclusion*, etc. Storyboarding is part of the research process and should occur throughout the project, as illustrated in Figure 4.6 (page 185), to produce the desired work(s).

There is no single method for storyboarding a document. Some people storyboard on paper with separate pages for each section. They then organize each section, shuffling information to more appropriate sections. Other people use software in much the same way. *Scrivener* is a commonly used electronic storyboarding software, and illustrated in Figure 5.4.
Still other people have an electronic document with just the headings. They input information directly into that document. Regular review and reorganization of the information allows you to draw connections between data, link your results to what is already published, and identify areas where more research/investigation is required, and generally progress to the complete document.

The document preparation flowcharts in sections 5.7 to 5.10 contain a storyboarding section similar to Figure 5.5.

**STORYBOARD the document**

- analyze the data/notes
- determine the document sections
- prepare figures, images, and graphs
- write point-form notes on the data, observations, and understanding
- expand the notes into paragraphs

- organize the notes and paragraphs into sections
- rearrange the notes to produce a cohesive story
- add, remove, and move items as required

cycle through these storyboarding points

**Figure 5.5** The process of storyboarding.

As your document nears completion, it may be beneficial to lay out the complete draft document and have others review and provide feedback on the content and organization. Figure 5.6 illustrates this for a large document — possibly a capstone report.

... redacted in preview ...
5.4 Laboratory reports

The laboratory report is the first document produced after an experiment is conducted. Depending on what you are doing, you will usually prepare a complete report or a summary report.

A complete report is prepared the first time an experiment is conducted. It contains all the sections detailed below. Complete reports are required for validation, accreditation, and to teach new persons how and why an experiment is done in a particular manner. The complete report forms the basis for the report given to a client and is the starting point for scholarly articles. For example, forensics laboratories prepare complete reports to validate their results; lawyers target the methods used in forensic laboratories with the hopes of discrediting the results.

A summary report is prepared when the analysis is routine. That is, a complete report has already been done for the experiment and only different samples are being tested. The summary report refers to the complete report for the theory, materials, and procedure and focuses on the results, discussion, and conclusions from that particular experiment. Examples include medical tests, weather reports, and environmental reports.

In addition to laboratory reports, science writers commonly prepare progress reports and project reports. Progress reports are interim reports prepared as part of large research and investigative projects. Project reports are reports prepared at the end of major projects that involve many experiments.

Sections in a laboratory report

... redacted in preview ...
• Discussion
• Conclusion or Summary
• Bibliography or References or Works cited

Some instructors, employers, and publishers prefer the sections numbered. Sections may also be combined: Introduction and theory, Materials and methods, Results and discussion. The Hazards section can be integrated into the Materials section when the hazards pertain to the materials themselves, such as chemicals or equipment, and the combined materials and hazards may be tabulated. Hazards associated with the procedure can be integrated into the Methods section.

The Abstract is a concise overview and summary of the theory, experimental method, and key results. The Abstract must itself be a complete document as it is often read separately from the entire report.

A well-written Introduction informs the reader that you understand the nature of the experiment and how it fits into the bigger scientific picture. A detailed Theory section indicates you understand the science behind the experiment. Detailed Results and Discussion sections illustrate your ability to analyze and interpret the data in the context of the underlying theory, and convey its importance to science and society.

When preparing a laboratory report, it is often valuable to start with the section you are most comfortable with — often the Materials and methods or Results section — and then move to other sections. You will find that as you write, your understanding and ability to explain other sections improves. Expect to move between sections as you complete the report.

Progress and project reports
... redacted in preview ...
Progress reports also provide the writer — from the student working on a term essay, to the undergraduate or graduate student involved in research, to the research supervisor of the research program — with an opportunity to review and reflect on the work completed. Future work can be planned to complete the project more efficiently. Progress reports also serve as a starting point for preparing other documents.

Progress reports to a supervisor are typically short, one to three pages, and could alternatively be in the form of an oral presentation. Progress reports to funding agencies are typically longer.

Progress reports often form the basis for the project report, which draws the results of the individual experiments into a coherent document for the reader.

*Project reports*

Large research projects are common in universities and in industry, while large investigative projects are common in university, industry, and government. For example, science graduate students design and conduct a research project under the direction of a faculty member. Each student’s project is part of the faculty member’s larger research program.

Project reports will be read by a broad audience: scientists, engineers, managers, accountants, government officials, reporters, and the public. Quite often, these people will not read the entire report, focusing instead on the section(s) that is interesting or important to them. Thus, every section of the report should be reasonably self-contained so that it can be understood without reading the entire report.

*Formatting reports*
Reviewing reports

You want your report to be free of errors, easy to understand, and interesting. Appendix A lists questions you should keep in mind when preparing your report. Additionally, ensure the readability statistics are appropriate for the audience (see Table 5.1). Once you have prepared your report and reviewed it once or twice, have one or more colleagues review it and provide feedback. Give reviewers the Appendix A questions and ask them for recommendations to improve the report. Chapter 6 provides more information on the review process.
A clear, concise title that accurately reflects the content of the report and is understood by a broad scientific audience.

name, date

Abstract
A concise overview and summary of the theory, experimental method, and key results. The Abstract should place the current experiment in the context of the greater research project, if applicable. The Abstract must itself be a complete document as it is often read separately from the entire report.

(up to 1/4 page)

Introduction
An overview of the experiment conducted, the objective(s) of the experiment (often in the form of a research question), the rationale for the experiment being conducted, and relevant background information to put the experiment in the context of the larger project. The introduction sometimes ends with a one-sentence summary of the conclusion, “I found that …”.

(1/2 – 2 pages)

Theory
The theoretical foundation underlying this experiment. From the theory, one can predict the experimental outcome.

(1/2 – 1 page)

Materials
The equipment and supplies used to conduct the experiment. For equipment, include the make and model and any modifications. For supplies, include the manufacturer and lot number.

... redacted in preview ...
Method or Procedure
A detailed description of how the experiment was conducted, including instrument settings during data collection. A schematic of the experimental setup aids in understanding. The procedure must be complete enough that anyone with similar training can conduct the experiment.
Note: a laboratory manual lists the steps necessary to complete the experiment; a Methods section is written in paragraph form as a process.
($\frac{1}{2}$ – 2 pages)

Results
This section presents the data obtained and the analysis of that data. Data are commonly presented in tables and graphs; use chemical and/or mathematical formulae to explain how the results are derived from the data.
($\frac{1}{2}$ – 2 pages)

Discussion
This section presents a detailed interpretation of the results in the context of the research question. This is the most important section of the report, as understanding is only achieved when meaningful information is extracted from the data.
($\frac{1}{2}$ – 2 pages)

Conclusions
This section summarizes the key points from the results and discussion and relates the results to the experiment objectives.
(up to $\frac{1}{2}$ page)

Bibliography or References or Works cited
A list of the resources you used to prepare the report. Common references

... redacted in preview ...
A clear, concise title that accurately reflects the project and is understood by a broad scientific audience

Progress report to <date> name

Introduction
An overview of the project that is a summarized version of the Introduction in the original proposal (section 5.6). The Introduction should focus on the component(s) (experiments or investigative steps) of the project that you are working on. The introduction does not change between progress reports unless there is a change in the project plan. (¼ 1 page)

Results
For each component that you are working on, focus on the work since your last progress report.

• Summarize the work completed to date. Compare the work completed against the schedule and budget in the proposal.

Timeline: <descriptive project title>

<table>
<thead>
<tr>
<th>week:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-project 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-project 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

today

... redacted in preview ...
5.5 Article summaries

As you progress through your education and career, you will need to read and summarize the work done by others. An article summary (précis) is a 1/2- to 2-page document that summarizes the important aspects of a scholarly article, usually following the same order and logic as the article. The summaries provide you with a shorter document to review when refreshing your memory of the article. Students may be required to submit an annotated bibliography as part of a term essay. An annotated bibliography is a collection of article summaries.

An article summary is not an extraction of key sentences into another document. A summary requires you to understand what the scientists have done and what knowledge they obtained from their research, and explain it in your own words. A summary extends beyond the reported work to include your opinion of the work and its importance to your project. Your summary should answer several questions:

1. Why was research conducted?
2. What research was conducted? (the research question)
3. What are the benefits and limitations of the research method?
4. What knowledge was gained from this research?
5. What questions are still unanswered?

Question 5 could easily set the stage for your own research project!

Sections in an article summary

The following sections are common in summaries, but variation is also common depending on the nature of the article and the information you

... redacted in preview ...
Flowchart for preparing an article summary

read article

without referring the article, write a paragraph on the key purpose and results of the article

do both, the order is up to you

reread to understand the method, data, and results

summarize the method, data, and results

prepare a cohesive summary from your notes

add your observations about the article

reread to understand the discussion and conclusion

summarize the discussion and conclusion

Figure 5.7 A flowchart outlining the steps to preparing a research article summary.
Formatting an article summary

Article summaries are produced with minimal formatting. See page 206 for guidelines on formatting these documents.

Citation management software

It may be convenient to prepare the summary using citation management software that electronically organizes your resources and summaries. Common citation managers include ProCite, RefWorks, and EndNote. These programs

• store the full citation of the resource
• store an electronic copy or link to the resource
• store your summary
• are searchable
• integrate with online databases to obtain additional scholarly articles as required
• integrate with word-processing software to automatically generate the Bibliography or References or Works cited section of your work in the required style

Learning and using one of these programs will save you a lot of time, energy, and frustration if you are conducting a long-term project.

Reviewing article summaries

Article summaries are not normally published. However, they may be assigned as course assignments or be required in an annotated bibliography.

You want your summary to be free of errors, easy to understand, and... redacted in preview...
...article summary...

A review of
<complete citation of paper>

name, date

Overview
The first sentence should present the key result(s) of the article.
The remainder of the Overview should summarize the theory, explain why
the research was conducted, and place the research in the context of the
greater scientific field.
(up to $\frac{1}{2}$ page)

Research method, data, and results
A summary of the research conducted and the results thereof. While these
may be in separate sections in the original article, they should be blended
together in the summary for concision.
The last paragraph in this section could be your observations on the method
and analysis, or this could be included in the Personal observations section.
($\frac{1}{2}$ – 1 page)

Discussion and conclusions
A summary of the knowledge gained from the research and the importance,
benefits, and limitations of the research.
The last paragraph in this section could be your observations on the
discussion and conclusions, or this could be included in the Personal
observations section.
($\frac{1}{2}$ – 1 page)

Personal observations
Your professional opinion of the article: what was good, poor, and
interesting about the article? Is there any potential bias based on the author.
... redacted in preview ...
5.6 Research proposals

Money is required to conduct and disseminate research, from purchasing equipment and supplies, to paying researchers and assistants, to travelling and presenting at conferences. Scientists apply for funding from government, private, and corporate agencies. In every application, the scientist must make a persuasive argument for why they deserve funding.

A research proposal is a sales pitch to funding agencies for money to conduct research. The research proposal must show that you have conducted a thorough literature review and have thoroughly thought out the research you propose to do. In essence, you must sell your research as a valuable advancement of science and show that it will benefit society. A panel of scientists in the same field reviews the proposals — nuclear physics proposals are reviewed by nuclear physicists, etc. — so your proposal must be targeted to specialists in the field.

Most funding agencies receive more applications than they have funds for, so the reviewers are looking for reasons not to fund your research! Your application must be clear, coherent, concise, precise, and persuasive, and the project must be within the funding mandate of the agency. You need to sell your idea, your abilities, your confidence, and your enthusiasm to the reviewers.

How you prepare your proposal depends on the audience. Proposals prepared for government funding agencies should focus on how the work will advance science and improve understanding. Extravagant claims and grandstanding will be questioned. Proposals prepared for private and corporate agencies should promote the accomplishments of the researcher(s). Be aware that private and corporate agencies (and ... redacted in preview ...}
Your proposal is a legally binding document. You are not agreeing to get the results you propose, but you are agreeing that you have the ability to complete the project and will commit the resources, personnel, and funding to the project.

When applying for funding, you must use the application form of the agency to whom you are applying; your application must contain all the required information; and you must follow their guidelines regarding format and length. Recall that the reviewers are looking for reasons not to fund your project. Sample forms can be found at

- NSERC: http://www.nserc-crsng.gc.ca (Canada)
- SSHRC: http://www.sshrc-crsh.gc.ca (Canada)
- NSF: http://www.nsf.gov (United States)
- NIH: http://www.nih.gov (United States)

The template research proposal below contains sections that are commonly required by funding agencies.

**Reviewing research proposals**

You want your proposal to be free of errors, easy to understand, and interesting. Appendix A lists questions you should keep in mind when preparing your proposal. Additionally, ensure the readability statistics are appropriate for the audience (see Table 5.1).

Once you have prepared your proposal and reviewed it once or twice, have one or more colleagues review it and provide feedback. Give reviewers the Appendix A questions and ask them for recommendations to improve the proposal. Chapter 6 provides more information on the review process.

... redacted in preview ...
... research proposal ...

A clear, concise title that describes the proposed research, the investigated variables, and the research methodology

Collaborators
The scientists who will be working with you on this research project. List their qualifications and the resources they have available to contribute to the project.

Summary
A plain-language summary targeted to the public, focusing on the societal impact of the proposed research. Prepare the Summary as a freestanding document, because it will be published separately if the research is funded.

(up to 1/2 page)

Abstract
A technical summary targeted to the scientific reviewers. It should include the research question, the hypothesis, and summary of the research design and expected outcomes. Reviewers often read the Abstract first, so it should be clear and persuasive.

(up to 1/2 page)

Introduction
A review of the relevant scientific literature in this area, limitations of the previous research, and how your proposed research builds on the previous research. Show how your research is significant and important — remember you are trying to sell yourself! Indicate how this research fits into your research interests and other research projects. This section should cite numerous peer-reviewed sources, including yours if you are active in this

... redacted in preview ...
... research proposal ...

Research plan
A detailed description of the research you wish to accomplish, the research question, research design (the types of experiments to be conducted, the source of samples, the equipment to be used, and how the data will be analyzed), expected practical and/or theoretical outcomes, and the strengths and limitations of your research plan.
(1 – 2 pages)

Facilities and equipment
List the facilities and equipment required to conduct the experiment, and their location. If the facilities or research site are not at your institution, attach documents confirming permission to use the facilities or access the site. (This is not required if the facilities are affiliated with a collaborator. If facilities must be reserved (such as ship time or satellite time), attach documents confirming pre-approval to reserve the facilities.)
(up to 1 page)

Ethical approval
If the research involves living organisms, including human subjects, the proposal must include proof that an independent Institutional Review Board has reviewed and approved the research plan (see section 4.5).
(attached as appendix)

Schedule
A timeline for the research: obtaining equipment, set-up and testing, data collection, data analysis, and reporting. If there are multiple scientists involved and the project has multiple facets, identify who will be doing which facet of the research. Use a chart to visualize the timeline.

Timeline: <descriptive project title>

... redacted in preview ...
Budget
A detailed list of the resources required to complete the research: salaries, equipment, materials, travel costs for fieldwork and meetings, and publication costs (conferences, etc.). List the funding expected or obtained from other sources and the funding requested from this organization. (1/2 – 1 page)

Benefits
Detail the expected benefits and/or deliverables of the research to the funding agency, to the scientific community, and to society. Also, detail the expected number of researchers and student researchers who will be involved in the research project. (1/2 – 1 page)

Summary
A closing paragraph that summarizes the importance of your proposed research and emphasizes your enthusiasm and confidence in successfully completing the work. (1/2 page)

Bibliography or References or Works cited
A list of the resources you used to prepare the proposal. Most of these should be scholarly articles. (as much space as required)
5.7 Scholarly articles, including essays and theses

A scholarly article* is the primary means of communicating your research to other scientists. Scholarly articles expand human knowledge as illustrated in Figure 1.4 (page 9). By their nature, they are highly technical documents.

A fundamental requirement of scholarly articles is that the articles undergo a rigorous peer review process prior to publication. Scholarly articles are reviewed by scientists who are independent of your research but who are knowledgeable in the field. The reviewers have significant power: they may recommend publishing the article as is, publishing with minor modifications, recommend additional experiments be conducted, or may recommend not publishing the article. The goal of this rigorous peer review is to ensure that the published work is of the highest quality.

Types of scholarly articles

Research articles are the most common type of scholarly article. They are prepared after the completion of a research project and provide a comprehensive report of that research to the scientific community.

Communications are shorter scholarly articles that quickly communicate profound results to the scientific community.

Review articles review and summarize what has been published in a scientific field and endeavor to summarize the current understanding of that field. It is common for review articles to be 50 or more pages and cite hundreds of references.

An essay (or report†) is the culminating document from an investigative project. Essays are routinely prepared for non-specialists in the field.

... redacted in preview ...
contribution of new knowledge, the others decreasingly so. What defines substantial? Your supervisor and defense committee decide that.

**Storyboarding a research article or communication**

1. **determine the topic**
   - collect data
   - is there sufficient data to tell the story?
     - no
     - yes

2. **STORYBOARD the document**
   - analyze the data/notes
   - determine the document sections
   - prepare figures, images, and graphs
   - write point-form notes on the data, observations, and understanding
   - expand the notes into paragraphs

3. **organize the notes and paragraphs into sections**
   - rearrange the notes to produce a cohesive story
   - add, remove, and move items as required

4. **cycle through these storyboarding points**

5. **is there sufficient data to tell the story?**

6. **write the first draft (just write; don’t edit)**

7. **submit to the desired journal**

... redacted in preview ...
The first draft is exactly that: a draft. The goal of the first draft is to collect all the information in one location and make obvious connections between the points. It does not need to be neat. Subsequent reviews by yourself and your colleagues correct the grammar, style, and add depth to the work.

**Sections in a research article**

Every scholarly journal has exacting specifications that must be followed when submitting an article to the journal. The recommendations below are representative of the journal requirements for research articles.

Like laboratory reports and research proposals, research articles have standard sections. It may be possible to modify your section headings to make them more informative and more appropriate to the discipline, article, and/or journal.

- **Title**
- **Author and author affiliation**
- **Abstract**
- **Introduction**
- **Materials and methods** or **Procedure**
- **Results**
- **Discussion**
- **Conclusion** or **Summary**
- **Appendices**
- **Bibliography** or **References** or **Works cited**

The *author list* is the names of people who have made intellectual contributions to the research. Write names as first name, initials, and... redacted in preview...
this scientific field. The Abstract also explains what research was conducted and the key results of that research. The Abstract must be a complete document, as it is published separately. On the internet, often only the title and abstract are available to readers without a subscription. They are also the only sections returned in a database search. The Title and Abstract must summarize and promote the document, convincing the reader that the full document is worth reading.

Because abstracts must be short, authors often find writing the Abstract difficult. Many leave it to the end, after the article has been written and the authors have a thorough understanding of what is included therein.

Omit extraneous text and superfluous phrases in the Title and Abstract. For example, remove phrases like “A study of ...”, “Investigations of ...”, “Observations on ...”, etc.

**Sections in communications and review articles**

Because communications are shorter documents meant to convey profound results, they typically focus on the Results and Discussion sections and only have a brief Introduction and Procedure, referring readers to their future research article.

The traditional headings are not applicable to review articles because the intent is not to present research, but to summarize the research conducted by many scientists. Persons writing review articles have more flexibility in determining section headings and often use headings that are descriptive of the information presented in the section.

**Formatting an article**

Different scientific disciplines have different preferred formats for
Page 206 has general guidelines to format documents. Specific formatting unique to scholarly articles is given below:

- **text**
  - 1.0 spacing (single spaced)
  - two columns with a 1.0 cm spacing
- authors and their affiliations as shown on page 237
- submission timeline as shown on page 237

A scholarly article formatted for publication is presented below.

**Reviewing scholarly articles**

A key feature of publishing scholarly articles is the peer-review process. If you publish scholarly articles, you are required to review scholarly articles published by others. Expect to review two to four scholarly articles for every article you publish. This obligation is part of your commitment to ensuring that only quality articles are published. This obligation extends to reviewing the work of your peers as you proceed through undergraduate and graduate school.

Appendix A lists questions you should keep in mind when preparing your article. Additionally, ensure the readability statistics are appropriate for the audience (see Table 5.1). Once you have prepared your article and reviewed it once or twice, have one or more colleagues review it and provide feedback. Give reviewers the Appendix A questions and ask them for recommendations to improve the article. Chapter 6 provides more information on the review process.

... redacted in preview ...
A clear, concise title that accurately reflects the content of the article and is understood by a broad scientific audience

Jessie A. Wang, Jamie B. Martinez, Taylor C. Müller, Riley D. Jensen

Received <date>; revised <date>; accepted <date>

A concise overview and summary of the research question, research design, and key results. The Abstract should inform the reader why the research is interesting, important, and relevant; how the research fits with and expands our knowledge in this field; what research was conducted; and the key results of that research. The Abstract must itself be a complete document as it is also published separately.

Introduction
A review of the relevant scientific literature in this area and how the current research — the subject of this scholarly article — builds on the existing research. This section should cite numerous peer-reviewed sources.

The Introduction should answer four main questions: What is already known in this area? What research was conducted? Why was the

Materials and methods
Write this section as a process: each step in order. It must be sufficiently complete so that anyone with similar training is able to conduct the experiment. A schematic of the experimental setup aids in understanding. If the procedure has been published, reference it, but still give a brief description and detail any changes.

When documenting a procedure for
were stored or handled prior to use in this experiment. Document all known hazards regarding the materials and procedures. Indicate the appropriate handling, safe use, and safe disposal procedures.

Results
Present the data obtained and the analysis of that data. Data is commonly presented in tables and figures, but do not present the same data in both a table and a figure. Chemical and/or mathematical formulae explain how the results are derived from the data.

While laboratory reports and theses require all data be presented, research articles and communications only contain representative data and calculations. (This saves publication space.) The journal may require all the data be submitted electronically so that it is available to others.

Readers accept that the analysis of the remainder of the data is similar to the sample shown. Explicitly state if some data or results are inconsistent with the majority of the data supported by the results!

Be sure to discuss the theoretical and practical applications of this new knowledge, and the significance to science and society.

Conclusion
Summarize the key points from the Results and Discussion.

Acknowledgements
Acknowledge those who provided assistance but are not authors on the document: those who provided samples, technical assistance, advice, .... Acknowledge organizations that funded the research.

Disclose any potential conflicts of interest.

Works cited
A list of the resources you used to prepare the article. Most of the resources should be peer-reviewed scholarly articles and scholarly books.

It is critical to double-check the citations; errors are surprisingly common.
5.7 Scholarly articles, including essays and theses

Storyboarding an essay or thesis

**determine the topic**

**STORYBOARD the document**

- analyze the data/notes
- determine the document sections
- prepare figures, images, and graphs
- write point-form notes on the data, observations, and understanding
- expand the notes into paragraphs
- organize the notes and paragraphs into sections
- rearrange the notes to produce a cohesive story
- add, remove, and move items as required

*cycle through these storyboarding points*

**is there sufficient data to tell the story**

**write the first draft (just write; don’t edit)**

cycles of internal review and revision by the author(s)

yes

- submit to the instructor
- submit to the committee

no

... redacted in preview ...
The first draft is exactly that: a draft. The goal of the first draft is to collect all the information in one location and make obvious connections between the points. It does not need to be neat. Subsequent reviews by yourself and your colleagues correct the grammar, style, and add depth to the work.

**Sections in an essay or thesis**

Essays and theses are formatted like a book. In a thesis, the section headings are similar to a research article, but draw together several experiments as part of the overall research project. Institutions provide guidelines and templates for students preparing theses. In an essay, the experimental chapters are replaced by chapters exploring the research conducted by others.

The goal of an essay/thesis is to logically and coherently draw together the existing knowledge and current research — including your own research, if you are writing a thesis — to increase the knowledge in the field. Essays and theses do not simply summarize the individual works, they analyze them to find commonalities and discrepancies to better understand the field. The discrepancies indicate areas where understanding is poor and could form the basis for future research projects.

There is often a word limit on essays. This limit refers only to words in the numbered chapters, *Introduction* to *Acknowledgements* (see below). Theses do not have a defined length — they thoroughly but concisely present all the research that was conducted. On average, the *Introduction* to *Acknowledgements* chapters of undergraduate theses are 20 to 50 pages, Master’s theses are 80 to 200 pages, and Doctoral theses are 150+... redacted in preview ...
5.7 Scholarly articles, including essays and theses

Formatting an essay or thesis

Essays and theses are produced with minimal formatting. Page 206 has general guidelines to format documents. Specific formatting unique to essays and theses is given below. However, if you are preparing a thesis and your department or institution has guidelines, those guidelines supersede these guidelines.

• title page with Title: 20 point font; bold
• headings
  ◦ Headings may be numbered in longer documents.
  ◦ Essays and theses may require additional heading levels:
    Heading 1: 16 point; bold; numbered; prefaced with “Chapter”; space after: 18; start on new page
    Heading 2: 14 point; bold; numbered; space before: 18; space after: 6
    Heading 3: 12 point; bold; space before: 12; space after: 3

Alternatively, essays and theses may be formatted like a book.

Below is an example of an essay and of a thesis formatted for submission. Each section details the information expected in that section. The essay is assumed to be a student essay submitted as part of a degree program. However, as noted on page 218, essays are commonly prepared for other purposes such as project reports. In these circumstances, sections unique to student essays are not included.

... redacted in preview ...
A clear, concise title that accurately reflects the content of the essay and is understood by a broad scientific audience

by

<author>

in partial fulfillment for the requirements of <course>

at

<iinstitution>

... redacted in preview ...
Abstract
A concise overview and summary of the problem you are investigating and the key results. The abstract should inform readers why the investigation is interesting, important, and relevant; how the investigation fits with our knowledge in this field; and the key results of the investigation.
The Abstract must itself be a complete document as it is also published separately.
(The Abstract is on its own page. 100 – 300 words)

Table of contents
A table of contents that lists the chapters, headings, and numbered subheadings and their page numbers. Appendices are included in the Table of contents.
Appendix B of Communicating Science explains how to use styles, which will dynamically create and update your Table of contents.
See, for example, the table of contents of Communicating Science.
(The Table of contents is on its own page(s).)

The above sections either can be without page numbers or numbered using roman numerals. If using roman numerals, the title page is page i, the Abstract is on page iii, and the Table of contents on page v (assuming a double-sided document). However, do not show the page number on the title page.

Executive summary
A longer overview of the report with the technical details minimized and the results and recommendations emphasized. The format and headings of the Executive summary are similar to the overall report, including the repetition of important tables and figures. Emphasis is on the importance, benefits, conclusions, and recommendations of the project. The Executive summary is typically 5 – 10 % of the total report length.
(The Executive summary is on its own pages and numbered using roman numerals.)
2. <Information from literature: source 1>
This chapter presents the information you discovered during your investigation. You must present the information in a clear and logical manner so that the reader can follow your logical progression to the conclusions you plan to draw later in the essay.
Since the information comes from other sources, this section must cite these sources.
(Each information chapter is 10 – 20 % of essay.)

3. … <Information from additional literature sources>
Repeat the steps in Chapter 2 for each source.

7. Discussion (assuming chapters 2 – 6 explore different literature sources)
This section draws connections between the information presented in previous chapters and explains how it addresses the problem identified in the Introduction. You can also explore the broader implications of your investigation to science and society.
The Discussion should be thorough, but concise, and should avoid repeating information presented elsewhere in the document.
(30 – 40 % of essay.)

8. Conclusion
Summarize the key points from the discussion and reiterate how your investigation addresses the problem identified in the Introduction. Ensure that the conclusions you draw are supported by the information you present!
(≈ 5 % of essay.)

9. Acknowledgements
Acknowledge those who provided you with assistance. Acknowledge any
A clear, concise title that accurately reflects the content of the thesis and is understood by a broad scientific audience

by

<author>

in partial fulfillment for the requirements of <course or degree>

at

<institution>

... redacted in preview ...
A clear, concise title that accurately reflects the content of the thesis and is understood by a broad scientific audience

We accept this thesis as conforming to the required standard.

<Committee member 1>  <Committee member 2>

... redacted in preview ...
Abstract
A concise overview and summary of the research question, research design, and key results. The abstract should inform readers why the research is interesting, important, and relevant; how the research fits with and expands our knowledge in this field; what research was conducted; and the key results of that research. The Abstract must itself be a complete document as it is also published separately.
(The Abstract is on its own page, without page numbers. 100 – 300 words)

Table of contents
A table of contents that lists the chapters, headings, and numbered subheadings and their page number. Appendices are included in the Table of contents.
Appendix B of Communicating Science explains how to use styles, which will dynamically create and update the Table of contents, List of figures, and List of tables. See, for example, the table of contents of Communicating Science.
(The Table of contents is on its own page(s).)

List of figures
A table that describes every figure, graph, and image, and their page numbers. It is reasonable to reproduce the figure captions in the List of figures.
(The List of figures page is optional. If used, it is on its own page(s).)

List of tables
A table that describes every table and their page numbers. It is reasonable to reproduce the table captions in the List of tables.
(The List of tables page is optional. If used, it is on its own page(s).)
The *Introduction* should answer four main questions: What is already known in this area? What research was conducted? Why was the current research conducted? What are the key results of the current research? Answering this last question foreshadows the results.

The goal of the *Introduction* is to convince the reader that the current research makes an important contribution to the field.

(The *Introduction* starts on page 1. 10 – 20 % of thesis.)

2. **Materials and methods** or **Procedure**

If your research used multiple similar methods, include the common aspects of the methods in this chapter and the unique details in the appropriate chapters.

If your research used many different methods, state this and move the *Materials and methods* information into the appropriate chapters.

For each experiment, give a detailed description of the equipment and supplies used to conduct the experiment. A schematic of the experimental setup aids in understanding. For equipment, include the make and model of the equipment, any modifications to the equipment, and the instrument settings during data collection. For supplies, include the manufacturer, lot number, and how the supplies were stored and handled prior to use in the experiment. Document all known hazards regarding the materials and procedures. Indicate the appropriate handling and safe use procedures.

Write this section as a process: each step in order. It must be sufficiently complete so that anyone with similar training is able to conduct the experiment. If the procedure was previously published, reference it but still give a detailed description and document any changes.

(10 – 20 % of thesis.)

3. **<A short description of an experiment you conducted>**

3.1 *Introduction*

... redacted in preview ...
3.3 Results
Present the data obtained and the analysis of that data. Data is commonly presented in tables and figures, but the same data is not in both a table and a figure. Chemical and/or mathematical formulae explain how the results are obtained.

All the data collected should be included in the thesis. If there is a lot of data, include representative data in this chapter and all of the data in an Appendix. Data can also be included in electronic form on a CD or DVD, which is valuable if the experiment generated considerable electronic data, such as computational, modeling, and image/video data.

A well-formatted and comprehensive results section is critical as it forms the basis for showing the importance of your work.

3.4 Discussion
This section presents a detailed interpretation of the results in the context of the research questions and relates this new information to existing knowledge. The Discussion should be thorough, but concise; avoid repetition of information presented elsewhere in the document. Ensure that the statements you make are supported by the results you obtained!

(Each experimental chapter is 10 – 20% of the thesis.)

4. … <A short description of an experiment you conducted>
Repeat the steps in Chapter 3 for each experiment conducted.

8. Discussion (assuming chapters 3 – 7 describe different experiments)
This section draws together the individual discussion sections and applies the information to the overall research project. The Discussion should discuss the theoretical and practical applications of this new knowledge, and its significance to science and society.

The Discussion should be thorough, but concise; avoid repetition of information presented elsewhere in the document. Ensure that the
9. Conclusion
Summarize the key points from the Results and Discussion sections and reiterate how your research draws together and builds upon the existing knowledge in this area. Ensure that the conclusions you draw are supported by the information you present!
(≈ 5 % of thesis.)

10. Future work
Your research provides an incremental step toward better understanding this field of science. This section explains how your experiments could be improved to obtain better data and experiments the next person working in this field could conduct to further this work.
(< 5 % of thesis.)

11. Acknowledgements
Acknowledge those who provided you with assistance. This includes your research supervisor and everyone who assisted with any aspect of your research project: provided samples, equipment, scientific advice, ….
Acknowledge the organizations that funded the research.
Disclose any potential conflicts of interest.

Works cited or Bibliography or References
A list of the resources you cited when preparing the thesis. Most of the resources should be peer-reviewed scholarly books and scholarly articles.
It is critical to double-check the citations; errors are surprisingly common.

Appendices
Appendices contain all the experimental results and specialized information not critical to the discussion, but important to those conducting similar
5.8 Scholarly posters

A scholarly poster is a predominantly visual presentation of your research/investigative project. The limited space on a poster means you must focus on one or a few key aspects of your project.

Storyboarding a scholarly poster

Since posters are a predominantly visual document, storyboarding the information and layout on paper is especially important and will save you time when you begin creating the poster.

completed laboratory report
or scholarly article

STORYBOARD the poster and presentation

- identify the key aspects of the research/investigation
- identify the information that should be on the poster
- tweak the figures, images, and graphs for the poster
- determine the sections of the poster
- organize the information into sections
- rearrange the information to produce a cohesive story
- add, remove, and move items as required

cycle through these storyboarding points

cycles of internal review
and revision by the author(s)

... redacted in preview ...
A poster requires the project to be complete. You should have prepared either a complete laboratory report or essay on your project. This gives you a comprehensive understanding of the information, what it adds to the current understanding of the field, and its importance in society. You need this in order to

• understand the entire scope of the work
• identify and extract the key information for the poster
• draw upon the full understanding when presenting the poster
• answer questions on related topics

Layout of a scholarly poster

If your institution, department, or research group has a poster template, use it! Templates commonly have the institution logo and the fonts pre-configured. If you are starting from scratch, I recommend preparing your poster in Microsoft PowerPoint®, Adobe Illustrator®, CorelDraw®, or Microsoft Publisher®.

Posters are predominantly visual, with text supporting the figures, images, and graphs. Ensure the text occupies no more than 60% of the poster area.

Posters typically start in the top left and conclude in the bottom right, consistent with how we read. Headings help guide the reader from section to section.

The poster session organizers will state the recommended and/or maximum poster size. Common sizes include

• 1.0 m × 1.5 m (40" × 60")
• 1.0 m × 1.2 m (40" × 48")

... redacted in preview ...
Headings*

The templates in Figure 5.11 list numerous headings. The headings you use will depend on your discipline and the specific nature of your poster. In many cases, you will combine headings or use different headings.

*Title*: choose a title that fits on one line and is likely to attract visitors to your poster.

*Author and Institution*: include the first and last names of all of the authors and their institution(s). Underline the name(s) of the presenting author(s).

*Logo*: the institution’s logo is always on the poster. The second picture could be the departmental or research group logo, or group picture.

*Introduction* or *Overview*: a short overview of the project. Keep it brief and interesting. Answer the following questions:

- Why was the research/investigation conducted (background)?
- What research was conducted (the research question)?
- What knowledge was gained from this project?

Include a picture if the picture helps to explain your motivation for conducting this project. (Aim for fewer than 200 words.)

*Materials and methods* or *Procedure*: a brief overview of the experimental design and equipment used. A schematic or flowchart is aids in understanding. (Aim for one or two figures and/or fewer than 200 words.)

*Results* and *Discussion*: these sections should be the bulk of your poster. Summarize the data in tables and figures. Use captions to explain each table and figure. The text should focus on interpreting and explaining the significance of the data. (Aim for up to five tables and figures... redacted in preview ...)
Other headings

Acknowledgements: list organizations and colleagues who assisted with funding, equipment, scientific advice, and/or logistical support. Funding bodies commonly have logos that you may use to acknowledge their support. Disclose any conflicts of interest in this section. (Aim for fewer than 40 words.)

Future work: given the results you are reporting in this poster, what are the next steps for the project?

Contact information: for visitors wanting more information, include your email address and the group website, if one exists. Ensure your poster, in PDF format, is available on the website.

The poster session

Posters are typically presented at a poster session, where tens to hundreds of people present posters at the same time. You have — at most — a few minutes to convey the key aspects of your work to visitors.
scientific poster

Communicating Science

Roy H. Jensen, University of Alberta

Colors
Color figures are great. However, use color sparingly in text. The focus must be your work, not on the colors and/or decorations in the poster. Posters with bright colors are hard to read.

Background: use one or two pastel colors or a faded background image related to your topic as a watermark to unify the poster. Try to integrate the background into the figures, images, and graphs.

Colorblindness: five percent of the population has some form of colorblindness. Red-green is most common.

Text
To be engaging
• write in the active voice
• present information in bullets and short sentences
The majority of visitors are not specialists in your field.
Use plain language (avoid jargon and acronyms) and focus on educating the average visitor. For the visitors who specialize in the same field, your verbal presentation will show your detailed understanding.
The text should compliment and explain the figures, images, and graphs.
Additionally,
• use line spacing of 1.0 or 1.5 (1.0 is single spacing)
• use capitals sparingly (capitalize proper nouns and only the first word in the title and headings)
• aim for a total word count of fewer than 800 words

**Printing your poster**

If the poster is for a course or a science fair, individual pages can be printed on normal paper and glued onto a larger poster board. When preparing this type of poster, consider printing in landscape.

If the poster is for presentation at a conference, the poster should be printed as a single sheet using a wide-format printer. Laminate the poster if you are going to use it at several conferences.

Transport the poster in a poster tube.

---

**Figure 1.** (top) Red, green, and blue sections with the same intensity. (bottom) Converted to greyscale, these colors are the same. Colorblind people experience this merging of colors, losing information in the image.

[http://jfly.iam.u-tokyo.ac.jp/color/](http://jfly.iam.u-tokyo.ac.jp/color/) provides suggestions on how to use color so that it is viewable by most people.

Yes, this poster needs more images!
As a presenter, you do not have a captive audience. Your poster must grab the attention of the people at the poster session. Once you have attracted them to your poster, you must converse with the visitors in a manner that interests and engages them. Your enthusiasm is important! You want visitors to leave with a good impression of you and the work you have done. This means the project must be relevant, it must be presented in a logical and concise manner, and you must have a good understanding of the project and related scientific field. Visitors may provide feedback on what you have done, recommendations for alternate analyses, and suggestions on future steps for your project.

**Presenting your poster**

Stand beside your poster so the visitors can see the poster!

When a visitor approaches, smile, but do not launch into your presentation. Casual visitors will read either the *Introduction* or *Conclusion* or look at the figures. These parts of your poster must engage and interest the visitor. Once they have had 10 – 15 seconds to review your poster, you can ask them,

- Do you have any questions?
- Would you like to hear about my project?
- How much do you know about <your topic>?

*Ask with enthusiasm!*

Visitors will usually spend a maximum of two to three minutes viewing your poster. Asking, “how much they know” provides you with information on their current level of understanding. You can then tailor your presentation to build on their understanding. Your presentation could be a formal presentation or an interactive conversation, depending ... redacted in preview ...
they understand what you are presenting. If they appear confused, stop and begin a conversation that may better inform them about your work. Section 5.11 provides strategies for giving presentations and answering questions effectively, and lists questions commonly asked by visitors.
Reviewing posters

You want your poster to grab the attention of the visitor, be free of errors, be easy to understand, and be interesting. Keep the questions in Appendix A and below in mind when preparing your poster and presentation.

**Layout:** this review should take about 60 seconds.

- Is the overall appearance inviting?
- Are the text and graphics aligned horizontally and vertically?
- Is there sufficient white space? Is it too crowded?
- Is there too much text? Too little text?
- Are there a reasonable number of figures, images, and graphs?
- Is the title catchy? Will it draw visitors?
- Is the title readable from three meters? Text from one meter?
- Is the flow of the poster obvious and easy to follow, *Introduction* to *Conclusion*?
- Are the key results easy to find?

**Content:** this review should take 10 to 30 minutes and the reviewer should read the entire poster a few times.

- Does the introduction grab the reader’s attention and explain the project?
- Does the *Conclusion* convey the key points of the project?
- Is the poster focused and on-topic?
- Is the poster trying to convey too much information?
- Is the text written using bullets and/or short sentences?
- Does the text complement the figures, images, and graphs?

... redacted in preview ...
• Is the presentation interesting and engaging?
• Can the presenter start at various locations in their presentation?
• Is the presenter confident about the information?
• Does the presenter handle questions professionally?

Once you have prepared your poster and practiced it a few times, have your colleagues review your poster and presentation. Give reviewers the Appendix A questions and the above questions and ask them for recommendations to improve the poster and presentation. Chapter 6 provides more information on the review process.

Additional suggestions
• Dress appropriately (business casual) and talk loudly enough for the visitors to hear you.
• Have business cards available to hand out during the poster session.
• Put your picture on the poster, in either the bottom left or right corner. This helps the visitors identify who the presenter is.
• Print mini versions of your poster printed on 8.5×11 or 8.5×14 paper. These can be handed out to persons who are interested in your work. (If prepared properly, your poster will be readable when shrunk to this size!)
• Print images in 3D and have 3D glasses available.
• If your poster is going to be unattended, use a mini audio recorder (like the ones found in greeting cards) to leave a message for visitors.
  ◦ “Press here for a 60 second overview of my poster.”
  ◦ Audio recorders can also be useful for supplementary material. For example, a presentation on animal communication could have multiple buttons, each with a sample of a different call.
• The poster session is a great way to network. If you find yourself... redacted in preview...
Southern Flounder Exhibit Temperature-Dependent Sex Determination

J. Adam Luckenbach, John Godwin and Russell Benko

Department of Zoology, Box 7807, North Carolina State University, Raleigh, NC 27607

Introduction

Southern flounder (Paralichthys ocellatus) exhibit sex determination and sex reversal as a response to environmental temperature and sex ratio. Flounder, in common with many other fish species, respond to thermal and hormonal cues to determine sex.

Objective

The aim was to determine whether southern flounder exhibit temperature-dependent sex determination (TSD) and if growth is affected by ovarian temperature.

Methods

- Southern flounder (Paralichthys ocellatus) were reared in controlled conditions with light and temperature cycles. Temperature was set to simulate the average temperature of the study area.
- Under natural lighting, 34 juvenile flounder were divided into two groups: one group was kept at a constant temperature of 18°C and the other group was subjected to a daily temperature cycle of 25°C/10°C.
- Growth was monitored over 30 days, and histological analysis was performed to assess gonadal development.

Results

- Growth rate was measured in terms of body weight gain, with a significant difference observed between the two groups.
- The body weight of the temperature-controlled group was significantly higher than that of the cyclic temperature group.

Discussion

- Growth does not differ by sex.

Conclusions

- Temperature cycling affects growth rate, with the temperature-controlled group exhibiting better growth.

Acknowledgments

The authors acknowledge the financial support from the National Science Foundation and the University of North Carolina at Chapel Hill for their contributions to this research. Special thanks to Dr. John Godwin for his guidance and support.
5.9 Preparing documents for other audiences

The style recommendations for the documents in sections 5.4 to 5.8 assume the readers are scientifically minded individuals. The documents have structures that scientists use and expect.

- A document intended for a scientific audience contains a logical process that leads from background → method → results → discussion → conclusion.

However, other readers do not have the same scientific background and have different interests in the scientific information, which must be considered when preparing documents for these readers.

- Administrators are often interested in the results and conclusions so they can make decisions. A document intended for an administrative audience often starts with the findings (results) and recommendations (based on the discussions and conclusions). The document then provides background and justification for the recommendations, with the methods and results often relegated to appendices. The Executive summary at the beginning of reports exemplifies this format.

- A document intended for a public audience often starts with a brief overview of the work and then goes into increasing detail for interested readers. This is seen in science magazines, newspapers, and encyclopedias.

Table 5.2 summarizes these differences.

Table 5.2 A comparison of documents prepared for scientific, administrative, and public audiences.

<table>
<thead>
<tr>
<th>scientific</th>
<th>administrative</th>
<th>public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Documents contain a</td>
<td>Documents start with the</td>
<td>Documents start with a brief</td>
</tr>
</tbody>
</table>

... redacted in preview ...
introducing misconceptions. Tables 1.8 and 1.9 (pages 41 and 43) list Latin and scientific terms and their plain-language equivalents. It may also be challenging to convince a scientist to prepare the document in a format expected by the audience, as illustrated in Table 5.2.

It is critical for scientists to communicate their research to non-scientists. For politicians and administrators, an understanding of the relevant science allows them to make sound and rational decisions. For the public, awareness of the importance and applicability of science in everyday society is important so that the public supports and demands independent
A primary goal when preparing documents for public audiences is to maintain scientific accuracy while translating high-level scientific terms and concepts into plain language.

**ACADEMIC LANGUAGE:** The linear integrity of the pipe was compromised. The biota exhibited a 100% mortality response.

**COMMON LANGUAGE:** The pipe was bent. All of the plants died.

**Storyboarding a document for public audiences**

- ** identify source scientific documents **
- ** STORYBOARD the document **
  - determine the important scientific information
  - determine the relevance to society
  - identify key scientific terms and equivalent plain-language terms
  - rewrite the science in plain language

- cycle through these storyboarding points
- cycles of **internal review** and **revision** by the author(s)
  - external review(s) by scientist
  - external review(s) by non-scientist

... redacted in preview ...
5.9 Preparing documents for other audiences

Reviewing a document prepared for another audience

You want your document to be free of scientific and grammatical errors, easy to understand, and interesting. Ensure the readability statistics are appropriate for the audience (see Table 5.1). Appendix A lists questions you should keep in mind when preparing your document.

Once you have prepared your document and reviewed it once or twice, have it reviewed by someone who understands the science and by someone who does not have a scientific background. Ensure they both reach the same, correct understanding of the science. Give reviewers the Appendix A questions and ask them for recommendations to improve the report. Chapter 6 provides more information on the review process.

“Global warming” and “Climate change”

Scientists have been investigating and documenting climate change for decades. There is overwhelming evidence that the Earth’s climate is changing slowly, over decades, and that the change is primarily caused by humans. Scientific climate models predict changing global weather patterns (some areas warmer; some areas cooler), an overall increase in average global temperature, an increase in extreme weather, and many other climate changes.

Instead of presenting all the technical data, climate scientists chose to focus on one consequence of climate change, global warming, because graphical data shows a gradual increase in average global temperatures since 1960. This increase correlates with increasing carbon dioxide concentrations. The scientists assumed that people would see the data, accept their conclusions, and advocate for change. However, climate change deniers used seasonal variations (cold winters) and localized cooler regions to seed doubt about...
5.10 Oral presentations

Oral presentations (colloquially called talks) occur frequently in science and in business. There are many types of presentations:

- **academic**: to inform others of your work and its importance
- **instruction**: to educate others and interest them in the information
- **proposal**: to obtain funding or permission
- **sales**: to encourage the audience to purchase what you are selling
- **self-promotion**: to a prospective employer or for promotion
- **team/group presentation**: to report on your individual progress to the other members of the team

As noted in Table 5.2 (page 264), the organization of your presentation depends on the intended audience.

A presentation requires a project to be complete. At minimum, you should have drafted and reviewed a complete laboratory report or essay on your project. This gives you a comprehensive understanding of the project, its contribution to the current understanding of the field, and its importance in society. You need this understanding so that

- you comprehend the entire scope of the work
- you can identify and extract the key information for the presentation
- you can draw on a full understanding when presenting
- you can answer questions on related topics

However, an oral presentation is not just a laboratory report or essay that you tweak into a presentation. An oral presentation presents information more like a poster than a written report. First, the limited presentation time means you must focus on one or a few key aspects of your project.
Storyboarding an oral presentation

1. **completed laboratory report or essay**

2. **STORYBOARD the slides and presentation**
   - identify the key aspects of the research/investigation
   - identify the information that should be in the presentation
   - determine the sections of the presentation
   - organize the information into sections

3. **revise based on feedback**
   - tweak the figures, images, and graphs for the presentation
   - rearrange the information to produce a cohesive story
   - add, remove, and move items as required

4. **cycles of internal review and revision by the author(s)**

5. **practice, Practice, PRACTICE!**

6. **external review by your colleagues**
   - ... redacted in preview ...

... redacted in preview ...
Presentation software

Presentations are predominantly done using presentation software. Common software includes Microsoft PowerPoint®, Apple Keynote®, OpenOffice Impress™, and Corel Presentations™. Each program allows for dynamic presentations with color images, videos, animations, audio, and transitions. Appendix B provides guidelines for using presentation software.

Whatever program you use to prepare your presentation, remember that the audience wants to know what you have done and why it is important. The audience is not interested in your abilities to use the numerous features in the software. Only use the features of the presentation software that are necessary to best present the material. This means minimizing the number of animations in the presentation.

Whatever technology you plan to use during your talk — data projector, overhead projector, whiteboard/blackboard/smartboard, flip chart, demonstrations, specialized software — make sure you are proficient in using that technology. Ideally, you should check the room a few days before your presentation to ensure the technology is available in the room and to visualize where to place the technology for maximum effect. Go to the back of the room and ensure the text and figures are visible and readable by those who will be sitting there. If time is available, practice giving the entire presentation in the room.

If you plan on writing during your presentation, make sure you write legibly and large enough so that your text is visible to the entire audience.

Planning your presentation

... redacted in preview ...
Learn by watching others: what did you like about their slides and their presentation? What did you not like? Use this knowledge to improve your slides and your presentations.

Section 5.11 provides strategies for giving presentations and answering questions effectively.

Team presentations

Team presentations add a layer of complexity. The team members must agree on what each will prepare and say. The presentation must be prepared so that it is coherent and the transition between speakers is smooth.

Slides

If your institution, department, or research group has a slide template, use it! Templates commonly have the institution logo and the fonts pre-configured.

The amount of time you spend on each section depends on how long you have to present. Budget approximately two minutes for every slide. As you gain presentation experience, you may find that you spend more or less time per slide and can adjust the number of slides accordingly.

- 15 minute presentations: 7 – 8 slides
- 20 minute presentations: 9 – 11 slides
- 45 minute presentations: 20 – 25 slides

While the focus of all presentations is the Results and Discussion, you should have

*Title:* 1 slide with the presentation title and listing the first and last name ... redacted in preview ...
presentations. If omitted for a research presentation, briefly present the methods orally prior to giving the results.

Results: 1 – 6 slides presenting the key results of your project. Tables and figures are preferred.

Discussion: 1 – 6 slides explaining the significance of the results, placing the results in context of the other research in your field, and illustrating the importance of your project to society.

The Results and Discussion sections may be combined.

Conclusion: 1 slide summarizing the important aspects of the project.

Acknowledgements: 1 slide listing all those who assisted with the project (colleagues and funding agencies). Include your contact information for those people wanting more information.

Numbering the slides is at your discretion, but conveniently allows the audience to quickly identify which slide they are interested in.

You can also prepare slides that answer frequently asked questions: additional data, details on the data analysis, future work, etc. These slides are not shown during your presentation, but are shown if someone asks an appropriate question. Having these prepared shows that you have put a lot of thought and time into preparing your presentation.

... redacted in preview ...
Preparing slides for an oral presentation

Roy Jensen, M.Sc., Ph.D.

<date>
<email address>

A presentation for inclusion in Communicating Science.

Outline

Slide templates
Fonts & style

These slides have more text because they need to convey information without a presenter!

... redacted in preview ...
Slide templates

Templates
- choose a template and use it for all slides
  - presentation software has templates
  - you can create your own unique template
- simple templates are often better and easier to work with
- look for ideas in presentations given by other speakers

- to make an important point stand out, *break the rules!*
  - use a different background, font, color, and/or animation.

Slide templates

Colors
- two template strategies are common
  - *dark text* on a light background
    ... redacted in preview ...
Slide templates

Colors

Five percent of the population has some form of color blindness.
- Eight percent of men are red-green colorblind.

http://jfly.iam.u-tokyo.ac.jp/color/ provides suggestions on how to alter images to make them viewable by most people.

Red, green, and blue sections with the same intensity.

Converted to grayscale, these colors are the same. Colorblind people experience this merging of colors, losing the information in the image.

Fonts & style

Font considerations

Use a single font for the title and headings, and another font for the text (the same font can be used for both)

... redacted in preview ...
## Fonts & style

### Common font sizes

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>44 – 72 pt</td>
</tr>
<tr>
<td><strong>Heading</strong></td>
<td>28 – 36 pt</td>
</tr>
<tr>
<td>General text</td>
<td>24 – 28 pt</td>
</tr>
<tr>
<td>General text may be indented</td>
<td></td>
</tr>
<tr>
<td>Bulleted subtext</td>
<td>24 – 28 pt</td>
</tr>
<tr>
<td>• bulleted subsubtext</td>
<td>20 – 24 pt</td>
</tr>
<tr>
<td>○ ditto</td>
<td>18 – 24 pt</td>
</tr>
<tr>
<td>1. Numbered subtext</td>
<td>24 – 28 pt</td>
</tr>
<tr>
<td>1. numbered subsubtext</td>
<td>20 – 24 pt</td>
</tr>
<tr>
<td>&lt;large spacer&gt;</td>
<td>24 – 28 pt</td>
</tr>
<tr>
<td>&lt;small spacer&gt;</td>
<td>10 – 12 pt</td>
</tr>
</tbody>
</table>

## Content

### Slide layout

- present information in bullets and short sentences
  - *maximum*: two lines of text per bullet (ideally one line per bullet)

... redacted in preview ...
Content

**Content**

- decide on two to four key concepts that you will focus on in your presentation
  - with more time, more concepts can be presented
- no more than one concept per slide
  - budget two minutes per slide
  - it may take more than one slide to present a concept
- focus on simplicity in your slides
  - as few points as necessary to convey the information
  - figures are excellent for conveying information
  - figures and tables without captions are fine: your presentation explains the figures and tables

---

Content

- only put essential information on the slides
  - *minimize text; MAXIMIZE figures*

... redacted in preview ...
Animations and transitions

- software has numerous animations to wow! the audience

**DO NOT USE THEM!**

- too many animations
  - detract from your presentation
  - annoy the audience, sometimes to the point that they ignore you
- when watching other presentations, note how too many animations get annoying quickly
- if you must, use simple animations to display additional information and transition slides
  - **Appear** and **Fade** won’t annoy your audience too much
  - **maximum**: three animations per slide (zero is a good number)

Figures (figures, images, and graphs)

- must focus on the information you wish to convey
- must be explained and emphasized to convey the

  ... redacted in preview ...
Content

Tables

- Must focus on the information you wish to convey
- If a report table has extraneous information, remake it to convey only the desired information
  - Magnify the table so the font is readable
- Use a figure if you want to show trends in data

<table>
<thead>
<tr>
<th>Document</th>
<th>Reading ease</th>
<th>Grade level</th>
</tr>
</thead>
<tbody>
<tr>
<td>graduate documents; scholarly articles</td>
<td>&lt; 30</td>
<td>&gt; 14</td>
</tr>
<tr>
<td>undergraduate documents</td>
<td>30 – 40</td>
<td>12 – 14</td>
</tr>
<tr>
<td>popular science articles; technical reports</td>
<td>30 – 50</td>
<td>10 – 14</td>
</tr>
<tr>
<td>general audience (newspapers, websites)</td>
<td>50 – 70</td>
<td>6 – 10</td>
</tr>
<tr>
<td>children’s books</td>
<td>&gt; 70</td>
<td>&lt; 6</td>
</tr>
</tbody>
</table>

Communicating Science 47 10

Content

Multimedia

- Multimedia — images, audio, and video — add realism to the presentation

... redacted in preview ...

... redacted in preview ...
Engaging the audience

Negative aspects of presentation software

Your presentation is the *story* of your work

Your primary goal is to inform others of your work

... redacted in preview ...
Engaging the audience

Presentation

- **minimize text; MAXIMIZE figures**
- your slides present key points
- your presentation expands on those points and develops the *story* of your research
- when you put up a slide, give the audience a few seconds to scan the slide
  - If the audience knows where you are going, they will pay attention to the *additional detail* you provide.

Handouts: some speakers distribute their presentation before they present. It gives the audience something to write on! But they can then skip ahead and read the conclusions before you get there.

Laser pointers

To effectively use a laser pointer:

1. *turn it on*

... redacted in preview ...
Review questions for presentations

1. Is the layout appealing?
2. Is there a reasonable amount of text and images per slide?
3. Is there a minimum amount of animations and transitions?
4. Is the presenter facing the audience?
5. Is the presenter adding content (not just reading the slide)?
6. Does the presenter spend a reasonable amount of time per slide?
7. Is the material presented in a logical order?
8. Is the presentation interesting and engaging?
9. Is the presenter confident about the material?
10. Does the presentation fit in the allotted time?
11. Does the presenter handle questions professionally?

Conclusions

The content of your presentation
• follows a template

... redacted in preview ...
Storytelling

The report-style presentation is a safe and effective linear presentation. The audience is led from point to point through the presentation. Linear presentations work with all audiences, but are they the most effective?

Shawn Callahan, a methods designer with Anecdote.com, relates a story about an IBM engineer who gave a presentation on privacy at a technology conference. The engineer presented seven key aspects of privacy and related two stories pertaining to privacy issues. Callahan, the next speaker, asked the engineer for permission to conduct a little test with the audience. It turned out that no one in the audience could recall more than two of the seven key aspects of privacy without referring to their notes. However, many were able to recall the fine details of both stories. (Adapted from www.youtube.com/watch?v=0A-8TPx1X50. Used with permission. Retrieved April 2011.)

Relating this to the constructivist learning model: data and facts have little context for readers to relate with. However, if built into a story that readers engage with, they more readily integrate the information into their understanding.

All cultures use stories to convey messages and morals. Good stories appeal to our emotions and have the power to persuade and motivate the audience. Stories are non-linear. Good storytellers, like novelists, weave together information in a way that engages the audience and draws them into the story. Some of the best storytellers are religious leaders. Some of the worst are scientists.

One problem with storytelling is that what you consider a good story is not everyone’s idea of a good story. If the audience consists of persons...
If done well, audiences find story-format presentations more engaging and more memorable. However, presenting in the form of a story is more challenging. Realize that

- A poorly presented report-format presentation will still convey information, but will bore the audience.
- A poorly presented story-format presentation will leave the audience confused — no information will be conveyed.

When preparing a story-format presentation, you will probably spend more time per slide. Change your slides to

- budget three to five minutes per slide
- *really* minimize the amount of text
- increase the number of visuals in your presentation
- have each slide present a chapter in the story

Like a story, your presentation must weave together the information in a way that engages the audience and draws them in. One difference between the report-format and the story-format is the concept of *surprise*. In report-format, you inform the audience of the conclusions early and then spend the remainder of the presentation explaining how your research/investigation came to those conclusions. In story-format, you build suspense throughout your presentation and only near the end of the presentation give the conclusions and their significance.

Put simply, the report-format presentation is a starting point for creating presentations. Once you are comfortable presenting your work, increase the amount presented in story-format. The key phrase is *comfort*: you must be knowledgeable in the information and comfortable in front of an audience.

* ... redacted in preview ...
Once you have prepared your presentation and practiced it a few times, present to your colleagues and have them provide feedback. Give reviewers the questions in Appendix A and on page 282 and ask them for recommendations to improve the slides and presentation. Chapter 6 provides more information on the review process.

**Figure 5.16** A visual representation of things to consider when preparing an oral presentation.
5.11 Public speaking

*Studies show that people’s greatest fear is public speaking!*
*The fear of death is second, and the fear of spiders third.*

You may not like speaking in public. However, if you wish to advance in your career, you will need to become a competent public speaker. The only way to do this is to speak publicly, and a classroom is the *safest* place to learn and hone these skills.

*To be an effective speaker, you must engage the audience.*

To gain competence and confidence in public speaking, you need to practice and you need to watch other speakers. Practice makes you more comfortable speaking publicly, increases your confidence, and allows you to speak with feeling and to connect with the audience. Watching other speakers will give you insights into strategies that improve their presentation (strategies you may wish to adopt) and mannerisms that detract from their presentation (mannerisms you should avoid). However, there is no substitute for practice.

Note that even professional speakers — politicians, ministers, and instructors — get nervous when speaking publicly. The key is to turn that nervous energy into enthusiasm for the presentation.

**Strategies for effective presentations**

*Believe what you are saying.* Sincerity is critical to credibility.

*Prepare speaking notes.* Your first set of speaking notes may be your...
... redacted in preview ...
Treat the audience as a group of peers. Use words and language that you would use when talking to your professional peers. Colloquial language draws the audience into your work: “I did this …”, “It was a surprise when …”, “From this, we see that ….”

Pauses add emphasis. Pauses give you time to breathe and the audience time to assimilate what you have stated. After showing a new slide, give the audience a few seconds to read the slide, and let them think about what you said and speculate on what you are going to say. (This engages them!) During the pause, maybe take a sip of water, but definitely take a deep breath before you start speaking again.

Add details and enthusiasm. If your slides are not too wordy, the audience will skim them to get an idea of where you are heading. You must then add context, details, and enthusiasm to what is on the slide. Your words and body language must express confidence and enthusiasm to draw the audience into your story.

Engage the audience. Design your presentation so that the audience gets involved in your presentation. Challenge them. Get them talking. Ask them questions. From their faces, you get real-time feedback on the level of engagement and can modify your presentation accordingly.
Use reasonable gestures. Non-verbal communication is critical to conveying enthusiasm and emphasizing key points. Hand and body motions, vocal inflections, and facial expressions are excellent non-verbal methods of doing this, but too many gestures distract from the presentation (see below). Realize that, in a large room, the people at the back will not be able to see your facial expressions, but they will be able to see your gestures. Make your gestures appropriate to your presentation.

Know and cater to your audience. What is the purpose of your presentation? Is the audience composed of scientists investigating similar phenomena? Are they a general scientific audience attending a departmental or conference presentation? Are they your fellow classmates or the public? What are the audience’s expectations of you? The audience dictates how much detail you can present and how technical your language can be.

Talk to the audience. Do not talk to the screen. Adjust the computer monitor so that you can look down at the monitor and up at the audience without moving. Stand off to one side to avoid blocking the screen from the audience. Standing on the side allows you to use a pointer and still face the audience. Each time you speak, scan the audience or look at a different section of the audience. When speaking to one or a few people, such as during a poster presentation, make eye contact with them.

Keep to time. The host will usually inform you when you have two or five minutes remaining and will cut you off when your time is up. If you are running late, skip slides and move to the key sections: Results and Discussion. If you have to skip slides, it means you did not practice enough.
If your presentation is too long, do not go faster, remove material!

Do not memorize your presentation and do not read off the slides. These presentations sound mechanical, lack emotion, and do not engage the audience.

**Distracting mannerisms**

As stated above, the occasional gesture is fine. Gestures are critical to conveying enthusiasm and emphasizing key points. However, repeating the same gesture throughout your presentation distracts the audience from your presentation. These distracting mannerisms become unconscious habits that you do without realizing and can alienate you from the audience.

Common distracting mannerisms include

- constantly clearing your throat or saying *um, ah, or like*
- speaking in a monotone voice
- constantly using your hands to emphasize statements (occasional hand gestures are fine)
- swaying from side to side or rocking forward and backwards
- gripping the lectern or tapping your fingers on the lectern
- repeatedly scratching a phantom itch or touching a part of your body
- constantly adjusting your clothes
- keeping your hands in your pockets, jingling keys, or coins
- constantly shuffling your speaking notes

Some hand motions may be perfectly fine in your culture, but are offensive in other cultures.

... redacted in preview ...
Controlling nervousness

Your heart is racing. Your hands are sweaty. Your body is vibrating. You have butterflies in your stomach. You are speaking rapidly.

*Adrenaline is a drug!*

You have just taken a big hit of adrenaline. Whether it is your first presentation or your thousandth, you are *nervous*.

STOP! Think about any sport you enjoy and big moments in a game.

- soccer  a free kick
- hockey  a break-away
- baseball  being at bat
- swimming  diving from the high diving board
- biking  going down a big hill
- going to school  taking an exam 😊

During these moments, you had adrenaline coursing through your body. How did you control it? Very likely, you panicked once or twice. However, you eventually learned to focus the adrenaline onto the task.

Public speaking is no different. Being nervous is normal. Use the following strategies to focus your nervous energy into giving an energetic and dynamic presentation.

- Be prepared to give the presentation — know the information and practice the presentation! This will give you confidence during your presentation.
- Before the presentation, engage in casual conversation with a few of the attendees.
- Take slow deep breaths before and during your presentation.

... redacted in preview ...
An important reason for learning and practicing presentations in school is that the environment is small and safe. These presentations give you experience and confidence. As you progress in school and your career, you will present on more challenging topics and in more challenging environments (like when your career depends on the presentation).

As you watch other speakers, you will see them become nervous and make errors. How do they correct for them? Are they successful?

Even with practice, you will find that you still become nervous before presentations. You may find that, once you start your presentation, you shift into presentation mode and channel your nervous energy into giving an energetic and dynamic presentation. You may even become excited about presenting because you like the feeling you have in presentation mode — akin to a runner’s high.

If you suffer from extreme anxiety, consider joining a speakers club, like Toastmasters™. They assist individuals in overcoming their fear of public speaking. As you gain experience and comfort in Toastmasters, you will help new members in the club. The best way to learn is to teach!

**Preparing for questions**

You should be able to answer the following questions about your project:

- What research/investigation was conducted?
- Why is this research/investigation important?
- How was the research/investigation conducted?
- What did each of the authors contribute to the project?
- What are the key results? Why are they important?
- How was the data analyzed?

... redacted in preview ...
Some of these questions may have been answered during your presentation. Your answer during the question period should provide more detail than what you gave during the presentation.

Anticipate questions the audience may ask and prepare answers. Include extra slides at the end of your presentation (possibly slides that you removed to shorten the presentation) to answer possible questions.

**Answering questions**

The following steps help you give the best possible answer and present yourself as a professional, attentive speaker.

1. Wait for the speaker to finish the question!
2. Repeat or rephrase the question. (This ensures the audience knows the question, focuses your mind on the question, and gives you a few seconds to formulate your answer.)
3. If you need to, take a few seconds to prepare your answer. It is better to speak succinctly than to ramble on.
4. Answer the question or state that you do not know the answer. (If you do not know — which is bad, but not as bad as fabricating an answer — ask for the speaker’s contact information so that you can get the answer to them.)
5. Ask if you have answered their question.

**Asking intelligent questions**

Questions request information or confirm understanding of information. Asking questions is *critical* to learning.

Conventional wisdom says that there is no such thing as a *stupid* question. However, it is a skill to asking *intelligent* and *appropriate* questions.
would be perceived as having a good understanding of the material, good articulation ability, and an active, engaged, or self-directed learner.

- a person
  - asking for the definition of a simple scientific term
  - asking a speaker a question that was answered in the presentation

would be perceived as not understanding the basic concepts and/or not paying attention, and a passive learner.

<table>
<thead>
<tr>
<th>Remembering Facts</th>
<th>Understanding</th>
<th>Analyzing</th>
<th>Applying</th>
<th>Creating</th>
</tr>
</thead>
<tbody>
<tr>
<td>What happened?</td>
<td>What is …?</td>
<td>What does the data tell us?</td>
<td>Show/explain …? How is … a solution to/ example of …?</td>
<td>Create an experiment that …? What would happen if …?</td>
</tr>
<tr>
<td>What is …?</td>
<td>How many …?</td>
<td>What do you think?</td>
<td>How is the data supported by theory?</td>
<td>Develop a theory that explains …? Propose a solution to …?</td>
</tr>
<tr>
<td>Define …</td>
<td>List …</td>
<td>How is this similar to …?</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>List …</td>
<td>Match …</td>
<td>How is this similar to …?</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>Relate …</td>
<td></td>
<td>How is this similar to …?</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>True or false: …</td>
<td>Explain …</td>
<td>How is this similar to …?</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>Describe …</td>
<td></td>
<td>Explain …</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>Who was involved?</td>
<td>Identify …</td>
<td>Describe …</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
<tr>
<td>Select …</td>
<td></td>
<td>Describe …</td>
<td>How is the data supported by theory?</td>
<td>What conclusions can you draw?</td>
</tr>
</tbody>
</table>

**Figure 5.19** Questions illustrative of the different levels of Bloom’s Taxonomy.

... redacted in preview ...
Prepare an intelligent question

Once a gap and/or inconsistency has been identified, the first step is to determine exactly what you do not know or understand. It is often convenient to work from what you do understand to what you do not. If time permits, consult resources like your textbook or the internet. You may find that doing this completes your understanding.

If you are still uncertain, you are now ready to ask a question.

Articulate your question

Each question should contain sufficient information that the responding person knows exactly what you are asking. Speak loudly, positively, clearly, concisely, and confidently.

Once you have the attention of the appropriate person and are ready to ask a question,

1. Set the context. Explain what you do understand or where you got confused. If the person was giving a speech or presentation, direct them go to the appropriate part of their presentation.

   Failing to set the context results in a vague question that leaves the recipient needing more information to appropriate answer it.

   Do you know first aid? (vague)
   Sam just cut his finger. Do you know first aid? (focused)
   We are looking for more first aid attendants. Do you know first aid? (focused)

2. Ask the question. Explain what you do not understand.

   We calculated the angle at which a curved road should be banked so that the force of the vehicle is directly into the road. I do not understand why roads are not constructed at these angles?

   ... redacted in preview ...
3. *Stop talking.* Let them answer. Listen to their answer.

Once they have answered, consider their response. It is permissible to ask one or two clarification questions. If you have the opportunity to ask multiple questions, progress from asking general questions to specific questions. If you have a complex question, asking a series of shorter questions is better than one nebulous question.

**Considerations when formulating your question**

*Be cautious with leading questions.* Leading questions contain one possible answer and my bias the person answering the question. Leading questions can be used effectively by instructors assisting students get an answer, and by law enforcement. If you want independent, impartial answer — commonly desired by researchers — do not use leading questions.

For question 7, did you get 150 IU as the dose? *(leading) ×*
I want to check my answer. What did you get for question 7? *(✓) *

So, are you saying that increasing atmospheric water vapor is a greater contributor to climate change than increasing atmospheric carbon dioxide? *(leading)*

*Ask open questions.* *Closed questions* require either a single word or short phrase answer. They assess the *remember* level of Bloom’s Taxonomy. *Open questions* require a longer answer, and can be written to assess all levels of Bloom’s Taxonomy.

Do you like analytical chemistry? *(closed) ×*
What subjects do you like? *(open) ✓*

How is the laboratory? *(closed or open) ×*
What is happening in the laboratory? *(open) ✓*
Asking a poor question. Everyone asks a poor question — where the answer is obvious or is completely off topic — once in a while. When you do, acknowledge the answer and thank the person answering the question.

Yes, that was obvious and I should have realized that. Thank you.
5.12 Other forms of communication

The preceding sections detail how to prepare common scientific documents and presentations. However, much of your communication will be informal communication with your colleagues and collaborators. You may answer questions from clients and the public, and communicate on behalf of your organization. You will be communicating with people around the world — people whom you have never met and whose first language may not be English. It is important that you are clear, coherent, concise, and precise in your communication.

**Memos, letters, and email**

Memos, letters, and email are the most common forms of communication.

- *Memos* are commonly sent to persons within an organization (colleagues, management, superiors, subordinates).
- *Letters* are commonly sent to people outside an organization (clients, customers, suppliers, government).
- *Email* is supplanting memos and letters as a means of rapidly communicating with one or more people.

These documents are used to inform, update, ask and answer questions, and make announcements. They are typically short and focus on one or a few related topics. While these are common documents and often sent to people whom you know, they still must be professionally written, with proper spelling and grammar, and with language tailored to the recipient. Always write in a polite, positive, and professional tone, even if expressing concerns: your correspondence represents you and your organization.

... redacted in preview ...
The message should concisely present the reader with the issue and their required action (if any). Two types of memos are common:

- announcements
- issue notifications

**Announcement memos**
The first paragraph is the announcement.
The next paragraph(s) identify any consequences of the announcement.
The last paragraph indicates to whom questions should be directed.

**Issue notification memos**
The first paragraph presents the issue and the desired action.
The next paragraph(s) provide details on the issue so that an informed decision can be made. Each paragraph should present different aspects of the issue. This information can be presented in point form. Detailed information (reports, budgets, timelines, etc.) may be attached to the memo.
The last paragraph summarizes the details, repeats the desired action, and explains why this action is recommended.
Write in a polite, positive, and professional tone, even when expressing concerns.
5.12 Other forms of communication

... letter template ...

ROY JENSEN

www.consol.ca
Roy.Jensen@consol.ca
119 Glencoe Boulevard
Sherwood Park, AB T8A 5J5
<date>

<address of recipient>
<address of recipient>

Attn: <recipient>
Re: <subject>

Letters are more formal than memos. I have taken the liberty of modeling this letter on my personal letterhead.

Letters have several sections:

• letterhead at the top contains the company name (or your name), logo, and contact information, including mailing address
• address contains the full mailing address of the recipient
• salutation identifies the recipient using their full name and title
• subject concisely states the content of the letter so that the recipient knows what your letter is about
• body presents the reader with the information you wish to convey. The format can be similar to the memo template.
• closing and signature personalizes the letter
• enclosures identify material attached to the letter
• cc identifies other recipients

There are two common letter layouts: block and modified block.

• block layout has all information left-aligned
• modified block layout has the date and closing to the right of center

... redacted in preview ...
Date: Tue, 8 Feb 2014, 13:46
From: Aiden Campbell <A.Campbell@McGill.ca>
To: Dr. Kelly Fischer <Kelly.Fischer@McGill.ca>
Subject: Research assistant position

Dr. Fischer

You may recall our conversation in your office regarding the research assistant position in your laboratory this summer. Attached is an application consisting of a cover letter, my curriculum vitae, and my academic transcripts.

The opportunity to work in your laboratory will provide me with valuable experience and I am confident I will be an asset to your research program.

Thank you,
Aiden Campbell

Fourth-year geology honors student
McGill University

Email software can automatically add electronic signatures. Use signatures to provide the reader with information about you that is not otherwise conveyed in the email. Signatures should be concise and well considered — they provide the reader with information about you.

Professional signatures should contain your name, position, and contact information.

Dr. Roy Jensen
(Lecturer, Chemistry
W5-19, University of Alberta
780.248.1808

... redacted in preview ...
Instructions and procedures

Section 5.9 explored strategies for conveying scientific information to public audiences. This section goes one step further: it addresses how to write instructions for public audiences so that they can complete a technical task safely. These tasks include determining the chlorine content of hot-tub water, handling corrosive cleaners, using and servicing power tools (saws, lathes, lawnmowers), and installing memory into a computer. An error in the instructions could cause injury or death, or destroy expensive equipment. You must write instructions that are clear, coherent, concise, precise, and at the level of the reader.

**Instructions** are detailed step-by-step directions on how to complete a task. Instructions are written for people with little or no technical knowledge.

**Procedures** detail the steps required to complete a task. Procedures are written for people with some technical knowledge and may omit fine details that a skilled person would know.

Laboratory manuals contain *procedures* for conducting the experiments and may contain *instructions* for operating specialized equipment.

Both instructions and procedures must be easily read and understood by the intended audience and must provide sufficient information so that the steps can be completely safely. When preparing them, complete and document every step, and repeat the process several times to ensure your documentation is complete. A video of the process is helpful so that you can review the video as you write the instructions or procedures. The following guidelines will help you prepare quality instructions and procedures:

- Write in the present tense.

... redacted in preview ...
Danger: advises of an imminent hazard that will result in severe injury or death.
Warning: advises of potentially hazardous situations, which, if not avoided, could result in serious injury or death.
Caution: advises of potentially hazardous situations, which, if not avoided, could result in minor personal injury.
Notice: advises of hazards that could result in non-personal injury, such as product or property damage.

Figure 5.20 Color-coding of safety symbols used to identify dangers, warnings, cautions, and notices in instructions.

Finally, detail each step. In each step, identify the purpose of the step, tools/equipment required, relevant hazards, and what the reader must do to safely complete the step. Each step must be numbered. A challenge when preparing instructions is to keep them clear and concise because many details are required.

When writing a procedure, you need to determine what technical skills the reader has; this determines the amount of detail required.

A procedure that involves a distillation would have several steps in a first-year laboratory manual, but would only require one-step in a fourth-year manual.

Often preceding a procedure is a description of the project and a list of

... redacted in preview ...
Conversations

Whenever you interact with someone, the people around you are forming and adapting their opinion of you. This occurs even if you choose not to interact. It is these opinions that determine if you are hired, promoted, perceived as friendly, perceived as intelligent, or the opposite. Conversations build relationships, create a trusting atmosphere, promote teamwork, promote learning and improvement, and solve problems. Questions are a natural aspect of conversations as they ensure everyone has the necessary information to complete their tasks.

Natural conversations are not all that ‘natural’. They require both parties to be focused on the conversation. Experienced communicators are constantly analyzing what everyone is saying (active listening) so that their contribution is relevant, meaningful, and moves the conversation forward. Below are some strategies to have better conversations.

0. Maintain positive casual relationships. This is an ongoing activity that acknowledges and shows respect for friends, colleagues, and clients. Say ‘hello’ to colleagues when you see them at work. If time permits, ask them how they are doing or what they are working on. Be sincere. These brief, informal conversations (small talk) allow people to get to know each other, which builds relationships.

When you see someone you know outside of work (store, park, sporting event, etc.), say hello, introduce them to the people you are with, and take a few seconds to discuss what you have in common — why you are at the same place.

With these casual relationships developing, you have a foundation from which to begin formal conversations. No-one leads a conversation, so it is everyone’s responsibility to ensure the conversation is a success.

... redacted in preview ...
4. **Promote participation.** Speak in a way that encourages others to participate. Some people need time to consider the discussion, identify information they can contribute, and then contribute. Questions arise naturally as people endeavour to understand their responsibilities.

5. **Change topics.** When a conversation is becoming uncomfortable or emotional, pause the conversation. Change topics or reschedule the conversation.

6. **In conclusion, summarize.** Ensure that everyone has what they needed from the conversation in terms of information and responsibilities.

**Meetings, phone calls, and video calls**

Chapter 1 explains that communication is 10% verbal or written and 90% non-verbal (tone, demeanor, dress, etc.). Written communication must be exact because the recipient does not receive the non-verbal cues. However, you convey non-verbal information during interactive events, from phone calls to in-person meetings. Humans are adept at noticing non-verbal cues: your clothes, posture, tone, eye movements, and a myriad of other cues inform the recipient of your interest, enthusiasm, and sincerity. Review sections 5.10 and 5.11 for strategies on how to effectively communicate orally.

Preparedness is important. Be prepared for meetings and scheduled calls by having read and printed the agenda and attachments, and by bringing a means of taking notes (pen and paper, computer, etc.). At the meeting, pay attention and involve yourself in the discussion when appropriate. Speak in a positive and professional tone, and stay focused on topic.

... redacted in preview ...
many years, order the sections: *Experience, Qualifications, Education.* Customize each résumé to the employer and to the specific position you are applying for.

A *curriculum vitae* (CV) is an academic résumé, provided when applying for teaching and research positions. A CV summarizes all the work you have done in your academic career: education, academic positions, research experience, teaching experience, publications, persons you supervised, and funding received to conduct research. There is no length limit on CVs, and it is common for CVs to be tens of pages in length.

Some people and institutions separate their teaching accomplishments from their research accomplishments. While a CV focuses on research, a *teaching dossier* summarizes your teaching philosophy, teaching experience, and contributions to pedagogy.

Templates for résumés, CVs, and teaching dossiers are available on the internet. Academic institutions may have CV and teaching dossier templates. Also on the internet are the résumés and CVs of thousands of people. Use these to guide the creation of your résumé, CV, and/or teaching dossier.

Spelling and grammatical errors in these documents suggest many things — none of them positive — and decreases your chance of being hired. Most institutions have a career center that will review your résumé and/or CV and provide feedback on content and formatting. Also, consider asking instructors in the discipline and people already working in the field to provide suggestions and review your résumé and/or CV.

All job applications should start with a *cover letter* that introduces you and personalizes your application to the prospective employer. It is the
Social media: public forums and blogs

Correspondence posted to online forums (Facebook, Twitter, discussion groups) and posted to your personal weblog (blog) is public. Everyone can read it: your colleagues, employer, future employer, and those intentionally wanting to pick apart your arguments (especially if you are posting on a controversial topic). What and how you post informs readers about your personality and how you interact with others. Posting well-reasoned, intelligent statements shows readers that you are competent and willing to engage in academic discussion. Posting extravagant statements or making demeaning or harassing statements says something else.

To illustrate the influence of social media, search for your name on the internet. How many people have the same name? Where are you in the list? For the hits that do represent you, what impression would another person, such as a prospective employer or your colleagues, form of you? Is that impression accurate? Do you like the public you?

Unless you are the designated spokesperson for your employer, postings are your own opinion. However, your postings reflect your personality, your attitude, and possibly your employer. Because of this, you must be extra careful about what you post and how you communicate it. All of your posts — personal and professional — must be written formally and professionally. Reviewing your post before submitting it is critical to conveying the desired message.

*Do not post in anger!* If you let your anger or frustration spill out, you will most certainly live to regret it. If you are posting on a controversial topic or disagree with what someone else has posted, wait. Wait. WAIT several hours to a few days before posting. Review what the other person has posted to ensure you have understood them correctly. Have a
Even if a reporter is asking questions, you must not answer if you are unsure about whether you are allowed. However, saying “no comment” suggests you have something to hide. The best response is to say, “I am not authorized to answer questions.” or “Please provide me with your questions in writing and <our organization> will respond promptly.” The latter strategy — asking for the questions — allows you to consider each question and provide a clear, coherent, concise, and precise response.

If your research is such that you want to share it with the media (a news release) or that the media may be interested in it, it is worthwhile identifying the key aspects of your research you wish to convey and repeating them during the interview(s). Respond promptly to all media inquiries because reporters are working on deadlines, and you probably want public recognition for your work.

When approached by a reporter, ask them to explain what story they are working on. This will allow you to tailor your answers to the story. In your verbal or written response, the following strategies will protect you and provide accurate information to the media.

• Be honest. Keep your answers brief and to the point.
• Be positive and professional. Reporters form an opinion of you based on their brief interaction with you. This opinion influences how they write their article.
• Speak only on topics that you are knowledgeable about. Stick to the key aspects of your research; do not guess or speculate on topics that you are not familiar with. Do not let the interview go off-topic.
• Speak in a positive and professional manner, even when dealing with a difficult situation.
• Remember that when speaking to a reporter, you are speaking to the... redacted in preview...
communicated during the interview. If the media report does contain minor errors, it is best to ignore them. If the report contains major errors, contact the reporter and positively and professionally inform them of the errors.

Finally, if you have been interviewed, inform others that should know, including any funding agencies, so they are aware and can be prepared for when the story is published.
Additional resources …

... on the process of science, including the scientific method, research methodologies, and scientific communication


... on writing a research article

Fischer B, Zigmond, M. Components of a research article [internet]. University of Pittsburgh. Available from: <no longer available>

Fischer B, Zigmond, M. Twenty steps to writing a research article [internet]. University of Pittsburgh. Available from: <no longer available>


... on preparing scholarly posters


Purrington C. Designing conference posters [internet]. Swarthmore University; 2009. <no longer available> An updated site is available at http://colinpurrington.com/tips/academic/posterdesign

... showing sample scholarly posters


... redacted in preview ...
... redacted in preview ...
Chapter 6. Peer review and peer evaluation

In your courses, you have learned the course material: biology, chemistry, earth science, mathematics, physics, English, etc. In addition, you were unconsciously evaluating the quality of the instructor, instruction, and course material. Did you like how the instructor taught? Was the textbook valuable to learning? You may have provided formal student feedback at the end of the course.

In Section 5.5, you were expected to assess the quality of scientific information in scholarly articles. In this chapter, you will apply these assessment skills to help your peers prepare quality documents and presentations. While this may feel uncomfortable at first, a classroom is the safest place to learn and hone these peer review skills, and these skills are critical for all professionals.

In your courses, you have likely experienced instructors deducting marks for spelling, missing or incorrect words, run-on sentences, and prose that does not make sense. Correcting these errors before submitting the document to your instructor would have improved your grade.

In your career, you will be required to prepare reports and give presentations to team members, management, clients, government officials, and the public. You want these documents and presentations to be of the highest quality; they cannot have errors. Poor-quality documents and presentations will negatively affect your company and could mean losing a contract or you losing your job.

Roger Communications Inc. and Aliant Inc. signed a contract whereby Aliant would string Roger’s cable lines. The contract states

... redacted in preview ...

... redacted in preview ...
6.1 Peer review

*Peer review* is the review of a colleague’s work to provide feedback and improve the work prior to publication/presentation. Peer review occurs during the development phase of a document and/or presentation.

The purpose of peer review *is not* to make another person *feel better* by giving them false praise for their work.

The purpose of peer review *is* to help another person *be better* by giving them constructive recommendations to improve their work.

In the context of *Communicating Science*, peer review means endeavoring to help your colleagues be better communicators by providing them with specific suggestions to improve their work. If you receive a positive peer review with only a few minor recommendations, it should be because you have prepared a quality work.
During the preparation phase shown in Figure 6.1, you prepare a work that is complete in terms of content and you review the entire work a few times to ensure there are no obvious errors in content and flow. At this point, you are most willing to accept feedback from reviewers to improve the work. Consider the alternative: if you tweak your work until you perceive it to be “perfect” and then give it to others to review, you will be more protective of your work and less willing to accept feedback.

While others are reviewing your work, put the work aside. Review it again yourself when you receive the external reviews. You may be surprised that what made sense when you were working on the document does not make sense now.

Plan for a minimum of two review cycles during the revision phase, with one or two different reviewers each cycle. The reviewers should have a basic understanding of the subject so they can provide recommendations consistent with the discipline. Ideally, each cycle will uncover fewer errors and the feedback will increasingly fine-tune the work.

- **First review cycle**: print the document double-spaced. This gives the reviewers space in the document for extensive comments. For presentations, print two slides per page.

- **Final review cycle**: print the document as the properly formatted final document. The reviewers can then review the document text, layout, and formatting. For presentations, print two slides per page.

For posters and oral presentations, once your document has been reviewed a few times, have your colleagues review your presentation. Considerations for reviewing presentations are on page 282.

You are not obligated to incorporate the reviewers’ recommendations into your work, but the reviewers did take the time to review your work...
Peer review in a classroom

It is often uncomfortable to effectively engage in peer review. However, peer review is a valuable skill to learn because it produces better work, improves writing and presenting skills, and teaches interpersonal skills. While this may feel uncomfortable at first, a classroom is the safest place to learn and hone these skills.

Respect and professionalism are critical to establishing peer review as a valuable and positive experience. You, your fellow students, and the instructor must work to establish a positive environment conducive to peer review — one where everyone feels comfortable working with each other and speaking out in class. Below are some strategies for getting comfortable with peer review:

1. Start by reviewing third party documents in small groups and as a class. Role-play giving constructive feedback.
2. Review draft scholarly articles from research faculty, with their permission. The class is now engaged in a genuine and valuable task. Have the authors attend and discuss the recommendations.
3. Review presentations by the instructor or invited speaker.
4. Review documents and presentations by fellow students. Start with short documents, and move to larger documents and presentations.

*Instructors:* some course management systems have the ability to coordinate anonymous peer review similar to that done by scholarly journals. However, these systems do not provide the opportunity for in-person feedback, which is also a valuable skill.

*Students:* in addition to learning these skills, you are learning about ... redacted in preview ...
6.2 Editing

Editing is the process of reviewing a document to make the language *clear, coherent, concise, precise, and correct*

Formally, there are several different types of editors.

- **Development editors** are involved in all aspects of document preparation, from making suggestions on what information to publish to large-scale writing and re-organization of the developing document. Development editors are common when completing large projects, such as books.

- **Substantive editors** organize and arrange the sections within the document to improve clarity; they may rewrite sections to improve readability and incorporate feedback from reviewers.

- **Copy editors** review the formatting, style, and grammatical structure of the document, but they do not check the information or substantively reformat the document.

- **Proofreaders** provide a final check of the document and identify spelling, grammar, style, and formatting errors not yet corrected.

In large organizations, you may encounter editors whose responsibilities cover one or more of the above roles. Professional editors and proofreaders are not specialists in the material they are editing — they are specialists in preparing quality documents. In large organizations, you and your colleagues may be called upon as reviewers. In smaller organizations, you and your colleagues will take on the roles of substantive editor, copy editor, proofreader, and reviewer.

In the publishing industry, editors will correct and format a document for publication. Your colleagues will not. Your colleagues will provide ...

... redacted in preview ...
<table>
<thead>
<tr>
<th>Text with error</th>
<th>Corrected text</th>
</tr>
</thead>
<tbody>
<tr>
<td>In February 2009, experiments testing the validity of Thomas' model were...</td>
<td>In February 2009, experiments testing the validity of Thomas’ model were...</td>
</tr>
<tr>
<td>sodium emission at 589.3 nm</td>
<td>sodium emission at 589.3 nm</td>
</tr>
<tr>
<td>travelling at 100 km/hr</td>
<td>travelling at 100 km/hr</td>
</tr>
<tr>
<td>melting point of 155–157 °C</td>
<td>melting point of 155–157 °C</td>
</tr>
<tr>
<td>Sample 3 — which should have the laser ionized the sample an angle of 125°</td>
<td>Sample 3 — which should have the laser ionized the sample an angle of 125°</td>
</tr>
<tr>
<td>live in either freshwater or saltwater</td>
<td>live in either freshwater or saltwater</td>
</tr>
<tr>
<td>In case of fire, immediately pull the fire alarm</td>
<td>In case of fire, immediately pull the fire alarm</td>
</tr>
<tr>
<td>accurate under ambient conditions. The compressibility, $Z$, measures the</td>
<td>accurate under ambient conditions. The compressibility, $Z$, measures the</td>
</tr>
<tr>
<td>use two 250 mL beakers</td>
<td>use two 250 mL beakers</td>
</tr>
<tr>
<td>confirmed a negative reaction enthalpy</td>
<td>confirmed a negative reaction enthalpy</td>
</tr>
<tr>
<td>Text with error</td>
<td>Corrected text</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>0.10 mol/L Hydrochloric Acid</td>
<td>0.10 mol/L hydrochloric acid</td>
</tr>
<tr>
<td>The large hadron collider in Europe</td>
<td>The Large Hadron Collider in Europe</td>
</tr>
<tr>
<td>the molarity (M) of a solution</td>
<td>the molarity (M) of a solution</td>
</tr>
<tr>
<td>let ( \mathbf{N} ) be a ( 2 \times 2 ) matrix</td>
<td>let ( \mathbf{N} ) be a ( 2 \times 2 ) matrix</td>
</tr>
<tr>
<td>[ E = mc^2 ]</td>
<td>[ E = mc^2 ]</td>
</tr>
<tr>
<td>The (largest change) was observed</td>
<td>The largest change was observed</td>
</tr>
<tr>
<td>[ F = ma ]</td>
<td>[ F = ma ]</td>
</tr>
<tr>
<td>[ C_1 V_1 = C_2 V_2 ]</td>
<td>[ C_1 V_1 = C_2 V_2 ]</td>
</tr>
<tr>
<td>The End</td>
<td>The End</td>
</tr>
<tr>
<td>Hydrothermal vents on the ocean floor support an abundance of life.</td>
<td>Hydrothermal vents on the ocean floor support an abundance of life.</td>
</tr>
<tr>
<td>( \vec{v} = 3.00 \times 10^8 \text{ m/s} )</td>
<td>( \vec{v} = 3.00 \times 10^8 \text{ m/s} )</td>
</tr>
<tr>
<td>0.25 mol/L CH₃COOH</td>
<td>0.25 mol/L CH₃COOH</td>
</tr>
</tbody>
</table>
Editing notation

The previous page lists many of the common symbols used by editors and proofreaders to identify errors in a document. These symbols are made either in the text or in the margin, at the preference of the reviewer.

- *Editors* prefer in-text editing because the document has more errors at this stage of development.
- *Proofreaders* prefer in-margin editing because the document is formatted in final form and the document (hopefully) has fewer errors.

When editing another person’s work, use a different colored pen — red or green — so your recommendations are visible.

In addition to editing and formatting text, a reviewer should also be reviewing the sentence and paragraph structure. Table 6.1 lists some common errors.

Table 6.1  Common word and sentence construction errors. See Chapter 1 for details. These symbols are circled, such as the font and font size recommendations on the previous page.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>sp</td>
<td>spelling error</td>
<td>agr</td>
<td>agreement problem</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(subject/verb or pronoun/antecedent)</td>
</tr>
<tr>
<td>awk</td>
<td>awkward construction</td>
<td>mm</td>
<td>misplaced modifier</td>
</tr>
<tr>
<td>rep</td>
<td>unnecessary repetition</td>
<td>shift</td>
<td>change in tense/aspect/voice/mood/person/number</td>
</tr>
<tr>
<td>rel</td>
<td>relevance?</td>
<td>![redacted](... redacted in preview ...)</td>
<td>incorrect parallelism</td>
</tr>
<tr>
<td>cs</td>
<td>comma splice</td>
<td>rom</td>
<td>roman font</td>
</tr>
</tbody>
</table>
When teaching, we use instructional strategies that mirror the learning stage we prefer. (We teach the way we learn.) If an instructor and student have similar preferred learning stages, the information being taught overlaps with the students existing knowledge, and the student is interested in learning the material, the student will find learning easier. When there is a disconnect between how the instructor teaches and how the learner learns or when the information is not linked to knowledge the learner already has, learning will be more difficult. The learner can still learn, but will feel somewhat frustrated in class. These are excellent opportunities to develop the other learning stages.

Figure 6.2  An extract from an early review of *Communicating Science* during the preparation phase. This is me — the author — reviewing my own work. The final text, which has undergone several additional revisions, is on page 146.
6.3 Giving and receiving feedback

One of the hardest things to do is *receive* feedback. Writers often take constructive suggestions as a personal attack and then defend themselves and their work. Even senior scientists, who have published dozens of research articles, may respond this way. It takes self-confidence, a positive mindset, and practice to keep an open mind when receiving feedback. Learning how to give and receive feedback is critical to a positive peer review experience, quality work, and a long, productive career.

Realize that the person giving the feedback is probably not comfortable giving feedback either. *Work together and help each other!* The person receiving feedback can provide the reviewer with suggestions to improve how they give feedback.

**Strategies for giving constructive feedback**

*Reviewers must provide constructive suggestions* to improve the work. Saying “this is bad” alienates the reviewer from the author. When reviewing the document, identify

- strengths of the document
- areas that require revision

By identifying areas (sentences, paragraphs, figures, tables, sections) that are well written and explaining what is good about them, the writer is informed of strategies they should continue to use. In areas that require ... redacted in preview ...
Considerations when giving feedback:
1. Give feedback as soon as possible.
2. Hold the feedback discussion in private.
3. Start the discussion by asking the author to self-assess: what are their thoughts on the document? What sections is the author proud of? Where do they think more work may be necessary?
4. For each section, give positive observations first, followed by recommendations for improvement.
5. Don’t be judgmental. Comments such as “This is poor” and “Have you even read this?” have no place in constructive feedback.
6. Use “I”-statements to take ownership of your feedback:
   - “I like …”
   - “I found …”
   - “I feel …”
   - “I believe …”
   - “I noticed …”
   - “In my opinion, …”
7. Take your time. Let the author think about your feedback before moving on. Ensure they understand what you are saying. Encourage them to ask questions at any time.
8. Don’t argue if the author rejects a revision — they may be getting frustrated or you may be wrong. Move on to the next recommendation or take a break.
   - “Okay, mine is only a suggestion. We can move on or take a break if you like.”
9. Don’t overwhelm the author with too many suggestions. This is why there are multiple review cycles: each successive review session identifies increasingly minor errors.
10. Observe the emotions of the author. Are they frustrated? Angry? ... redacted in preview ...
Peer review and peer evaluation

Strategies for keeping an open mind when receiving feedback

1. Constantly remind yourself that the feedback is for your benefit and the reviewer is trying to provide constructive feedback. Focus on positive emotions. Force yourself to smile and say “Thank you”.
2. Meet with reviewers one at a time.
3. Pay attention. Do not interrupt the reviewer when they are talking.
4. Acknowledge when the reviewer says something that you agree with (both strengths and problem areas in your work).
5. Summarize the feedback you have received to ensure you understand it correctly. Ask questions if you do not understand the suggestions.
6. Don’t take offense at the suggestions made by the reviewer. They are providing their opinion and constructive suggestions. If you disagree, ask for clarification, but do not openly argue with the suggestions.
7. Offer suggestions or advice to the reviewer, especially if they start making negative comments about your work.
8. Ask for a break if you feel yourself getting frustrated, angry, or emotional.
9. Don’t discuss the feedback session with others.

Finally, ask for feedback on how the session went. Does the reviewer perceive you as attentive and accepting of feedback?

*It is the mark of an educated mind to be able to entertain a thought without accepting it.* — Aristotle

... redacted in preview ...
6.4 Peer evaluation

Peer evaluation is the evaluation of a colleague’s document or presentation against established criteria. Peer evaluation occurs after a document is submitted and/or during the presentation and is meant to critically and impartially assess a colleague’s work. This is an important skill you will need in your future studies and career.

Throughout your career, you may be required to train new employees and to evaluate your colleagues. You will also be expected to provide management with an impartial and justifiable assessment of their performance. You may also be meeting with sales representatives and assessing their credibility and their product. As you advance in your career, you will be promoted into supervisory and managerial roles. Some of your responsibilities may include interviewing prospective employees, conducting training sessions, conducting job evaluations, and evaluating reports and proposals. Being able to impartially evaluate your peers is a learned skill. Proficiency improves with practice.

Impartial evaluation requires standards. Appendix D contains evaluation rubrics for the different documents and presentations in Communicating Science, and contains an evaluation rubric to assess feedback.

Additional resources …

... on giving and receiving feedback

Receiving and Giving Feedback [internet]. University of Waterloo. Available from https://uwaterloo.ca/centre-for-teaching-excellence/teaching-resources/teaching-

... redacted in preview ...
Appendix A: Review questions

Use the following questions to guide the development and review of scholarly documents. Note that some questions apply to only some types of documents and presentations.

Content
- What do you believe the key points of the document are?

Layout
- Are there any spelling or grammar errors?
- Does the Title reflect the nature of the project?
- Does the Abstract summarize the key findings?
- Does the Introduction provide a comprehensive and balanced review of the existing knowledge in the field?
- Does the Introduction explain why this project was conducted?
- Is there sufficient information in the Methods section for another person to repeat the experiment(s)?
- Is there sufficient information in the Results section for another person to repeat the analysis?
- Are the Discussion and Conclusion supported by the data?
- Are there any technical terms that have not been explained?
- Are there any errors in the mathematical and/or chemical formulae?
- Are there any errors in the data, analysis, or interpretation?
- Do the tables and figures succinctly present the data? Are they referred to in the text? Are the captions self-explanatory?
- Are the references at an acceptable scholarly level and cited properly?

... redacted in preview ...
Appendix B: Electronic document preparation

This appendix is an introduction to some of the functionality in word processing, spreadsheet, and presentation software, with a focus on the Microsoft Office® suite of products. This introduction assumes you have a basic understanding of Microsoft Word®, Excel®, and PowerPoint®. To use functionality not presented in this appendix, and to learn how to use other software, consult the Help and Tutorial features in that software or search the internet. It is likely that someone has needed the same functionality.

Table B.1 Keyboard shortcuts common to most productivity software.

<table>
<thead>
<tr>
<th>Keyboard*</th>
<th>Text commands</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL+N</td>
<td>new file</td>
</tr>
<tr>
<td>CTRL+O</td>
<td>open file</td>
</tr>
<tr>
<td>CTRL+S</td>
<td>save file</td>
</tr>
<tr>
<td>CTRL+P</td>
<td>print</td>
</tr>
<tr>
<td>&lt;arrow keys&gt;</td>
<td>move through text, one character at a time</td>
</tr>
<tr>
<td>CTRL+&lt;arrow keys&gt;</td>
<td>move through text, one word at a time</td>
</tr>
<tr>
<td>SHFT+&lt;left</td>
<td>right arrow&gt;</td>
</tr>
<tr>
<td>SHFT+&lt;up</td>
<td>down arrow&gt;</td>
</tr>
<tr>
<td>CTRL+A</td>
<td>select all</td>
</tr>
<tr>
<td>CTRL+C</td>
<td>copy selected text and/or objects</td>
</tr>
<tr>
<td>CTRL+X</td>
<td>cut selected text and/or objects</td>
</tr>
</tbody>
</table>

... redacted in preview ...
B.1 Word processing (Microsoft Word®)

Table B.2  Keyboard shortcuts in Word and other common word processing software.

<table>
<thead>
<tr>
<th>Keyboard*</th>
<th>Formatting Word® documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL+L</td>
<td>left-align paragraph†</td>
</tr>
<tr>
<td>CTRL+E</td>
<td>center-align paragraph†</td>
</tr>
<tr>
<td>CTRL+R</td>
<td>right-align paragraph†</td>
</tr>
<tr>
<td>CTRL+J</td>
<td>justify (left and right align) paragraph†</td>
</tr>
<tr>
<td>CTRL+SHIFT+S</td>
<td>change the style of the selected text or paragraph</td>
</tr>
<tr>
<td>CTRL+SHIFT+F</td>
<td>change the selected text’s font†</td>
</tr>
<tr>
<td>CTRL+SHIFT+P</td>
<td>change the selected text’s font size†</td>
</tr>
<tr>
<td>CTRL+SPACEBAR</td>
<td>remove paragraph or character formatting</td>
</tr>
<tr>
<td>CTRL+‘+’</td>
<td>superscript</td>
</tr>
<tr>
<td>CTRL+‘=’</td>
<td>subscript</td>
</tr>
</tbody>
</table>

* On Apple® computers, the CTRL key is the command key, ⌘.
† You should not need these commands if you use styles to format your document.

View

Of the possible views of your document, two are most common:
- **Print Layout**: provides the layout of your document when printed
- **Web Layout**: provides the layout of your document as web content

For the documents described in Chapter 5, Print Layout should be used.

Word documents contain numerous formatting characters hidden in the text. The default mode is to show only the printed text. However, it is sometimes necessary to see these formatting characters, especially if... redacted in preview...
Additional information and strategies for a clean document:

- *Do not* use Enter to put space between paragraphs, use Spacing:After and Spacing:Before in the paragraph style (see below).
- *Do not* use multiple tabs to align information: ➜ ➜ ➜ ➜<info>
  Set the desired tab stop in the style (see below).
- “Special formatting” is commonly found in headings and includes Keep with next, Keep lines together, and/or Page break before.
- Use Widow/Orphan control on all paragraphs.
- Hidden text is shown with a dotted underline.

**Page setup**

The Page Setup advanced settings (.Getenv icon) on the Page Layout ribbon allows you to set the paper size, paper orientation, and margins. You can control how these settings, headers, and footers apply to odd and even pages and the first page of each section.

... redacted in preview ...
Sections

If you are making a complex document with multiple chapters, different types of page numbering, different headers or footers, different page orientations, or different numbers of columns, you will need to break your document into sections. The properties of each section can be adjusted independently. Select the Breaks drop-down box on the Page Layout: Page Setup ribbon to insert different types of breaks. To change the type of section break, use the Layout tab in the Page Setup dialog box.
If an organization or journal provides a template with the styles pre-defined, use it! Otherwise, use this section to create your own template.

The Styles advanced settings allow you to view, edit, and create styles. Hover over the style to see the configuration. Right-click and select Modify to configure the style to your requirements.

- **Paragraph** styles format both the paragraph and all the text within it. Common paragraph styles include Normal, Heading 1/2/3, List bullet 1/2/3, List number, Table/figure captions, Header, and Footer.

- **Table** styles format the information in tables.

- **Character** styles format selected text within a document. Select text using the SHFT+arrow keys or use the mouse.

For ease in reading and formatting, it is best to use a limited number of styles. If you use styles properly, you should not have to use the Font and Paragraph dialog boxes on the Home ribbon. Proper use of styles also allows you to dynamically create a table of contents, table of figures, etc.
Formatting of the main styles in *Communicating Science*

**Paragraph styles**


**Heading 2**: Normal + 14 pt bold. Hanging: 1.0 cm. Space before: 18 pt; space after: 9. Single line spacing. Level 2 outline numbering. Numbered as ‘#.#’ (Level 1.Level 2)

**Heading 3**: Normal + 12 pt bold. Space before: 12; space after: 3. Single line spacing.

**Heading 4**: Normal + 12 pt italic. Space before: 9; space after: 3. Single line spacing.


**List**: Normal + left indent: 0.5 cm. Space before: 0. Single line spacing. No space between same style paragraphs.

**List bullet**: Normal + left indent: 0.2 cm. Hanging: 0.3 cm. Space before: 0. Single line spacing. Tab at 6.25 cm, centered. Bulleted: level 1.

**List bullet 2**: Normal + left indent: 1.0 cm. Hanging: 0.3 cm. Space before: 0. Single line spacing. Bulleted: level 2.

**List number**: Normal + left indent: 0.3 cm. Hanging: 0.6 cm. Space before: 0. Single line spacing. Numbered: level 1.

**Header**: Normal + 10 pt. Space before: 0; space after: 0. Single line spacing. Tab at 6.25 cm, centered.

**Example**: Normal + 10 pt + left indent: 0.5 cm. Space before: 0; space after: 6. Single line spacing. No space between same style paragraphs.

... redacted in preview ...
**Additional characters and symbols**

Tables 1.1 and 1.2 list additional characters commonly used in scientific communication. To insert these characters into your document, select the **Symbols:More Symbols…** icon on the Insert ribbon. This brings up the character map shown in B.4. In addition to inserting characters from this dialog, you can alternatively use the shortcut key indicated for the character.

![Figure B.4](image)

*Figure B.4*  The dialog box for inserting additional characters and special characters in Word. The default shortcut key is at the bottom center: 0382, Alt+X

**Fields**

*Fields* are a powerful but complex way to make a professional-looking document. The fields insert information about the document (such as the

... redacted in preview ...
Figure B.5  The Field dialog box. The list of possible fields is in the scroll region on the left.

Headers and footers

Every page has space at the top (header) and bottom (footer) for information that is constant throughout the section or entire document: page number, document name, your name, copyright information, section name, ....

Figure B.1 (page 329) shows that it is possible to have different headers and footers on odd and even pages and to have a different first page header and footer. By default, headers and footers keep the same properties as the previous section. This is usually a good thing, but must

... redacted in preview ...
Figure B.6 An odd-page header from Section 7 of *Communicating Science*. Hovering over the toolbar illustrates some of the fields that can be inserted: page number, date, etc. The colored Link to Previous icon indicates that the Section 7 heading is the same as the previous section heading.

To incorporate section headings into headers (or anywhere else in the text), use the `STYLEREF` field.

The even page heading of *Communicating Science* inserts the page number and Heading 1 with the field codes

```
output: 2 Communicating Science

code:  
   \{ PAGE \} \{ STYLEREF "Heading 1" \* MERGEFORMAT \}
```

The odd page heading of *Communicating Science* inserts Heading 2 and the page number with the field codes

```
output: 1.1 Elements of effective communication

code:  
   \{ STYLEREF "Heading 2" \* MERGEFORMAT \}.
   \{ STYLEREF "Heading 2" \* MERGEFORMAT \} \{ PAGE \}
```

The `\n` field code inserts the label from the selected style: “Chapter 1”. The `\t` field code suppresses all non-numeric text: the word “Chapter”. Pressing SHIFT+F9 toggles between the field output and field codes.

... redacted in preview ...
After selecting OK, the number “1” is inserted into your document. You can toggle between the field output and field code by pressing SHIFT+F9. The actual field code is

```plaintext
code:   { SEQ Table \* MERGEFORMAT }
```

Copy and paste the caption, then modify the caption text, for all subsequent tables. To update the numbering, select the entire document, CTRL+A, and then press F9.

To reference the table sequence in your document, select Cross-reference on the Insert ribbon, then select the Table reference type and the reference you wish to cross-reference. Be careful that you insert the information you desire: entire caption, label and number, page number, etc.

Table 1 contains the titration data.

If you are preparing a document with multiple chapters and appendices, you may wish to prepend the table number with the chapter/appendix number and you may wish to restart the sequence every chapter. All the figures and tables in *Communicating Science* have this format. To insert the current chapter number, the StyleRef field is used and field codes used to control what is inserted.*

```plaintext
output:  Table 1.1: <caption for Table 1>

code:    Table { STYLEREF "Heading 1" \n \t \* MERGEFORMAT }. { SEQ 
            Table \s 1 \* MERGEFORMAT }: <caption for Table 1>
```

Note that the table field codes have an additional \s #.

```plaintext
code:    { SEQ Table \s 1 \* MERGEFORMAT }
```

The \s # field code restarts the Table sequence after passing Heading #. In *Communicating Science*, Heading 1 is used for chapters.

... redacted in preview ...
Appendix B: Electronic document preparation

Figure B.8  The dialog box to change how the footnotes are separated from the text.

Spelling and grammar analysis

Before conducting a spelling and grammar analysis of your document, you need to configure the analysis at File:Options:Proofing. Adjust the settings to your preference or to the requirements of the instructor, employer, or publisher to whom you are submitting your work.

... redacted in preview ...
Ensure that the Show readability statistics button is checked. After a grammar check, a dialog box shows a readability analysis of your document. Table 5.1 provides information on interpreting the readability statistics.

![Readability Statistics Dialog Box]

**Figure B.10** Readability statistics of *Communicating Science*.

Note that the spelling analysis will not catch wrong words that are also words, which is why reviews are important.

<table>
<thead>
<tr>
<th>Word Pairs</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>breach, breech</td>
<td>than, that, then</td>
</tr>
<tr>
<td>if, in, is, it</td>
<td>wear, were, where</td>
</tr>
<tr>
<td>meat, meet</td>
<td>weather, whether</td>
</tr>
<tr>
<td>spell, spill</td>
<td>yore, your, you’re</td>
</tr>
</tbody>
</table>

Dew knot putt awl yore trussed inn spill chequers.

Additionally, do not automatically accept all of the corrections suggested by spelling and grammar analysis. The software is often unaware of scientific terms and phrases.

**Watermark (background)**

You can insert a color, picture, or text background using the Watermark: Custom Watermark… advanced settings on the Page Layout ribbon. Text... redacted in preview...
Some sample custom corrections are given below.

\[
dH \rightarrow \Delta_{\text{H}} \\
\text{GT} \rightarrow \text{Green's theorem} \\
\text{fff} \rightarrow \text{drosophilae}
\]

When you type the custom phrase and then press the Spacebar, Word automatically inserts the formatted text.

**Templates**

Setting all of the above parameters is a challenging and tedious task. Once you have everything configured properly, save the document as a template into the template directory. Once done, when you select File: New, your document will be one of the listed templates. If you want your document to be the default, save it as normal.dotx.

**Preparing a book**

Preparing a book-style work — an essay, thesis, technical report, manual, book, etc. — is an involved and time-consuming process. It is also a valuable learning experience and provides you with technical skills that you can use to improve all your documents. *Communicating Science* was created in Word. The following suggestions will help you create a professional-looking document.

- Use **Next page**, **Odd page**, and **Even page** section breaks to separate the front material from the body, to get the correct pagination between chapters, and anywhere else section breaks are needed to get the correct formatting. For example, **Continuous** section breaks allow you to change the number of columns of text in a section of the document.
- Modify the headers so that each section has the appropriate headings.

... redacted in preview ...
B.2 Spreadsheets (Microsoft Excel®)

Table B.3  Keyboard shortcuts in Excel and other common spreadsheet software.

<table>
<thead>
<tr>
<th>Keyboard*</th>
<th>Formatting Excel® documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2  (Mac: ⌘+U)</td>
<td>enter cell to edit text</td>
</tr>
<tr>
<td>TAB</td>
<td>move to next cell in the row</td>
</tr>
<tr>
<td>SHFT+TAB</td>
<td>move to previous cell in the row</td>
</tr>
<tr>
<td>ENTER</td>
<td>move to the next cell in the column</td>
</tr>
<tr>
<td>SHIFT+ENTER</td>
<td>move to the previous cell in the column</td>
</tr>
<tr>
<td>CTRL+&lt;left</td>
<td>right arrow&gt;</td>
</tr>
<tr>
<td>SHFT+&lt;arrow keys&gt;</td>
<td>select cells</td>
</tr>
</tbody>
</table>

* On Apple® computers, the CTRL key is the command key, ⌘.

Page setup

The Page Setup dialog is similar to Word’s, but there are additional tabs to set the header and footer and to define what sections of the sheet to print and if any rows/columns are repeated on every page. This is convenient if you have data that spans multiple pages.

Cells and cell formatting

Each worksheet contains a series of cells. Each cell is uniquely identified by a column letter and row number. The top left cell is A1.
Figure B.13  The tabs in the Page Setup dialog box.

... redacted in preview ...
Appendix B: Electronic document preparation

... redacted in preview ...
Rows and columns can be resized and hidden. Figure B.15 shows how to format selected cells. This method of setting the row height and column width ensures the selected rows and columns are all the same size. It is convenient to hide rows and/or columns containing intermediate calculations when producing publication-quality tables.

![Figure B.15 Formatting rows and columns.](image)

Publication-quality tables and figures can be created in Excel. All the tables and most figures in *Communicating Science* were created in Excel.

**Inserting functions**

Excel is designed to do math, from simple mathematical
In the cell, the formula starts with an equals sign, “=”.

$$=A1\times B1$$  $$=A1/B1$$  $$=\text{SUM}(A1:A4)$$  $$=\text{AVERAGE}(A1:A4)$$

Once a formula has been entered once, it is possible to replicate the formula for the other data in the series. The default action is that the cell reference moves relative to the cell. To make a formula reference a specific cell, such as a constant, no matter where the formula is copied,

- use a dollar sign in front of the letter to fix the column: $A1$
- use a dollar sign in front of the number to fix the row: A$1$
- use a dollar sign in front of both to fix the absolute position: A$A1$

There are several categories of formula:

- **mathematical functions**: mathematics, financial, statistical calculations
- **array functions**: matrix calculations
- **logical functions**: results depend on the content of other cells
- **lookup functions**: matching and finding data
- **text functions**: parsing and formatting text
Solver

Solver is a convenient add-in that fits your data to any equation you can enter into Excel. Solver adjusts the variables in your equation to minimize the difference between the data and equation.

Figure B.18 shows how the non-linear data in Figure 2.14 is fit to an exponential function, with the rate constant, $k$, being the variable that is adjusted by Excel.
Selecting Solver on the Data ribbon brings up the Solver dialog. (If Solver is not present, select File:Options:Add-Ins to activate the add-in.) In Figure B.19, Solver is set to vary cell E17 (the rate constant) to get a minimum in E16. This results in a non-linear function that best fits the experimental data. The guess value in E17 must be reasonable, and additional constraints can be added if required. Note that this example was simple, with only one varied value; it is possible to have Solver simultaneously vary several parameters in more complex functions to obtain the best non-linear fit to experimental data.
Figure B.20 The Chart Tools:Layout ribbon showing the icons for formatting a chart once created.

Make the following modifications to transform the chart into a scientific graph.

• Right-click the chart and Move Chart… to a new sheet. This provides you with more control over the size of the chart.

• Set the page margins to get the desired chart size. Start with 3.0 cm all around and 2.0 cm header and footer margins.

• Use the Labels and Axes icons on the Chart Tools:Layout ribbon to add axes (required) and a title (if required).

• To add additional data sets, right-click the chart and Select Data.…

• Double-click on a data point to format the data series.

• Right-click on the title, axes values, axes labels, or legend to format the font type and size.

• Double-click on the axes, gridlines, or plot area to format the line size and style.
Excel provides for significant customization of charts. Remember that simplicity is an important component of scientific graphs. Additionally, once you have configured a chart to your preferences, save the chart as a template. If you are making many charts with similar titles and axes labels, you can duplicate an existing chart, change the data, and modify the axes labels.

The graphs in *Communicating Science* were created using the parameters below. The values you use will vary, depending on your document.

- **text formatting**
  - *title*: 24 pt bold Times New Roman
  - *axis label*: 20 pt bold Times New Roman
  - *axis numbers*: 20 pt Times New Roman; minimum number of significant digits (not the number of digits in the data; see the footnote on page 96)
  - *text on chart*: 16 pt Arial

- **data points and lines**
  - *border lines of chart and axis tick marks*: 3.0 pt (triple width)
  - *data points*: 10 pt
  - *line size with data points*: 1.0 pt (single width)
  - *line size without data points*: 2.0 to 3.0 pt (double or triple width)

---

**Determination of iron(III) in water**

... redacted in preview ...
Pasting from Excel into other documents

When pasting a table or chart from Excel, the default is to paste as an HTML table that is editable in Word and PowerPoint. This does not keep the formatting of your Excel table and is not the best option for pasting tables and charts! To keep the formatting, the best option is to choose Paste Special and paste as a Picture (Enhanced Metafile). This pasting, however, does have a few nuances:

- You must hide gridlines before copying.
- You may need to copy an adjoining column or row to get the proper line widths. (This bug is new to Excel 2007 and 2010.)
B.3 Presentations (Microsoft PowerPoint®)

Table B.4 Keyboard shortcuts in PowerPoint and other presentation software.

<table>
<thead>
<tr>
<th>Keyboard*</th>
<th>Formatting PowerPoint® documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2 (Mac: ṭ+U)</td>
<td>enter text region to edit text</td>
</tr>
<tr>
<td>TAB</td>
<td>go to next object</td>
</tr>
<tr>
<td>SHFT+TAB</td>
<td>go to previous object</td>
</tr>
<tr>
<td>CTRL+D</td>
<td>duplicate selected object</td>
</tr>
<tr>
<td>SPACEBAR, PGDN, &lt;right</td>
<td>down arrow&gt;</td>
</tr>
<tr>
<td>BACKSPC, PGUP, &lt;left</td>
<td>up arrow&gt;</td>
</tr>
<tr>
<td>B</td>
<td>black screen</td>
</tr>
<tr>
<td>W</td>
<td>white screen</td>
</tr>
</tbody>
</table>

* On Apple® computers, the CTRL key is the command key, ṭ.

When preparing a presentation, you should create a slide template and use it for all the slides in your presentation. The sample presentation in Section 5.10 uses my slide template: simple, contrasting headings, and lots of space for information. Figure B.23 presents my Master Layout and my style guide.

Master layout

Select the Master Layout to edit the default slides. These slides establish the defaults for fonts, text areas, and the background of your slides. Adjust these to your liking and insert any graphics that should appear on

... redacted in preview ...
Appendix B: Electronic document preparation

**Communicating Science**

**Formatting guide**

<table>
<thead>
<tr>
<th>Component</th>
<th>Font Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heading</td>
<td>28 pt</td>
</tr>
<tr>
<td>General text</td>
<td>24 pt</td>
</tr>
<tr>
<td>General text may be indented</td>
<td></td>
</tr>
<tr>
<td>Bulleted subtext</td>
<td>24 pt</td>
</tr>
<tr>
<td>• bulleted subsubtext</td>
<td>20 pt</td>
</tr>
<tr>
<td>• ditto</td>
<td>18 pt</td>
</tr>
</tbody>
</table>

- Click to edit Master text styles
  - Second level
    - Third level
      - Fourth level
        - Fifth level

... redacted in preview ...
Creating a poster in PowerPoint

PowerPoint can be used to create a scholarly poster. To configure PowerPoint for your poster:

- **Start with a single blank slide.**
- **In Page Setup on the Design ribbon, select Custom Page Size and enter the desired dimensions of your poster.**
- **Adjust the font sizes on the Slide Master to the values in Section 5.8.**
- **Create textboxes for each text region.**
  - Textboxes should have the same width, but may have varying lengths, depending on your layout.
  - To format the textbox, right-click on the textbox and then select either Size and Position... or Format Shape... to configure the textbox size, color, position, and other formatting parameters.
  - Once you have properly formatted one textbox, it may be easier to duplicate it using CTRL+D
- **Ensure the textboxes are horizontally and vertically aligned, as illustrated in Figure 5.11 (page 253) and the sample posters starting on page 261.** There are several ways of aligning textboxes:
  - Visualize the Gridlines and use them as an alignment guide.
  - Select the textbox edge, then adjust the location using the arrow keys to move the textbox.
- **Insert figures as you would when creating an oral presentation.**
  - Ensure the figures are not distorted when resized.
  - Use vector formats if possible. If the figure is raster, ensure the resized figure has greater than 200 dpi resolution, which does not show pixelation.

... redacted in preview ...
Figure B.24  The Size tab in the Format Shape textbox dialog box.

... redacted in preview ...
B.4 Mathematical equations

The Equation Tools add-in allows you to create equations with proper mathematical syntax in all Microsoft Office® products. To create an equation, select Equation:Insert New Equation on the Insert ribbon. This creates a blank equation and opens the Equation Tools ribbon. The default is to create the equation as a floating object. By clicking on the equation, you can change this to an inline object.

Figure B.25  The interface of the Equation Tools editor and a sample equation.

On the right-hand side are mathematical structures, from fractions to mathematical operators. On the left-hand side are common mathematical symbols.*

The Equation Tools add-in has sufficient functionality to create most common mathematical equations. Most of the equations in Communicating Science could be created using Equation Tools. Below are a few more examples.

... redacted in preview ...
B.5 Electronic annotation

Annotating electronic documents is increasingly common since more resources are distributed electronically. However, it is often quicker to annotate printed documents than to annotate electronic documents. Section 6.2 provides information on hand annotation.

Annotating PDF files

The software available to annotate PDF files is dependent on the operating system and changes regularly. Selected programs are listed below. They have different features and different functionality. I recommend you read the online reviews and test several programs to find one that provides both the functionality you require and that you are comfortable using.

Windows

- Adobe Reader
- Foxit Reader
- PDF-XChange Viewer
- Sumatra

Mac

- Preview
- Adobe Reader
- Skim

iPad

- Adobe Reader
- Note Taker HD
- iAnnotate PDF
- PDF Expert
- Notability

... redacted in preview ...
Annotating Word® files

Before submitting your electronic document for review, select Tools:Track Changes to make Word record all changes to your document. Also select Tools:Protect Document..., then allow only Tracked Changes, and then Start Enforcing Protection. It is optional to enter a password, but a password ensures that the reviewers do not accidentally turn off Track Changes or otherwise edit the document.

The Track Changes mode causes Word to display the Reviewing toolbar in Figure B.29 and display a record of every edit made.

![Figure B.28 The settings to protect a document prior to giving it to a reviewer.](image)

Reviewers may do two things in the protected document:

- edit the document (add, delete, and format text)
- insert comments

Word assigns each reviewer a different color and uses different shades for edits and comments. When editing, new text appears in color and is underlined. Deleted text appears to the right of where it was deleted. Selecting insert comment, will insert a comment at the location of the cursor. If text is selected, the selected text is highlighted in color and the comment box appears at right.
Accepting or rejecting changes

Once you receive the file from the reviewer, you must review every change and determine if you will accept or reject the change.

First, unprotected the document by selecting Tools: Unprotect Document.…

Then, starting at the top of the document, select next change, 📢, read the reviewer’s recommendation, and then either select accept change, ✅, reject change, ❌, or move onto the next change if you wish to skip this recommendation for now.

Sample electronic annotations

Figure 6.2 (copied below) contains a section of hand-annotated text. This same text is annotated electronically using Adobe Reader in Figure B.30 and Microsoft Word in Figure B.31.

When teaching, we use instructional strategies that mirror the learning stage we prefer. (We teach the way we learn.) If an instructor and student have similar preferred learning stages, the information being taught overlaps with the students existing knowledge, and the student is interested in learning the material, the student will find learning easier. When there is a disconnect between what the instructor teaches and how the learner learns or when the information is not linked to knowledge the... redacted in preview...
When teaching, we use instructional strategies that mirror the learning stage we prefer. (We teach the way we learn.) If an instructor and student have similar preferred learning stages the information being taught overlaps with the students existing knowledge, and the student is interested in learning the material, the student will find learning easier. When there is a disconnect between how the instructor teaches and how the learner learns or when the information is not linked to knowledge the learner already has, learning will be more difficult. The learner can still learn, but will feel somewhat frustrated in class. These are excellent opportunities to develop the other learning stages.

**Figure B.30** Electronic annotation of the same text as in Figure 6.2 using Adobe Reader. To display new text and comments, the user must hover over each comment box and insert symbol, ▲.
Appendix C: Assignments

Practice is critical to improving your communication skills. As you practice writing, editing, and presenting, your abilities improve and your confidence increases. While the focus of *Communicating Science* is on scientific documents, the strategies developed herein can be applied to all aspects of life, from preparing your résumé to negotiating a car loan.

Below are assignments that build skills, experience, and confidence in preparing and presenting works. Most of these assignments can form the basis for in-class discussions and can be augmented with peer review and/or peer evaluation. Section 6.1 provides suggestions for establishing a safe environment where students are more willing to share openly and honestly. Instructors are encouraged to add context relevant to their instructional environment to make assignments that are meaningful to their students.

Many of these assignments ask you to use information from a science course you are taking or have taken. This strategy helps you integrate and apply your improving communication skills to a subject you are interested in. Moreover, you are learning more about the science subject!

**Introductory assignments**

1. Prepare a 20 – 30 second story about yourself that you will present during class. (The instructor presents first.)

2. In pairs, interview each other and prepare a 20 – 30 second story about the other person that you will present during class. (These should be template-based.)

3. Without using * Communicating Science* or other resources, prepare a... redacted in preview ...
2. Identify the nominalizations in Table 1.3.
3. Given a few of the undefined commonly confused word sets on page 49, define them. Do this in small groups, then present yours in class.
4. Search the internet to find examples of a cliché, idiom, tautology, circumlocution, pleonasm, and/or vague & imprecise word. Rewrite the sentence to improve readability. Share with the class.
5. Given # clichés, idioms, tautology, circumlocution, pleonasm, and/or vague & imprecise words,
   a) use Google Ngram to visualize the commonness of the phrase over time.
   b) search a scholarly database to identify phrases still in use and the discipline(s) they are used in.
   Discuss why the commonly used phrases are still in use.
6. Given the individual sentences from a paragraph out of order, order the sentences to produce a coherent paragraph. Identify the topic sentence of the paragraph.
8. Given a document, what revisions could be made to make the document more clear, coherent, concise, and precise?
9. Given a scholarly article, identify the key points of the article.
10. Given a scholarly article with references removed, identify sections of text that require citation.
11. Given a scholarly article with the abstract removed, prepare an abstract. Review and improve upon the abstract in the next class.
12. Given a scholarly article, write the “teaser” for a website or the front
17. Your company is considering cutting your project, which may mean you and your team may lose your jobs. Write a letter to the VP Research, explaining the importance of your project.

18. As a government investigator, you discover a product is unsafe. Write a letter to the company explaining the problem and what must be done to rectify the problem. (Instructor: provide <product, problem with product>.)

19. Given a public press article that misrepresents a scientific concept, write a letter that identifies the misrepresentation and correctly explains the science, at the level of the reader. Review and improve upon the response in the next class.

20. Given a public press article that denigrates science to further a political or corporate agenda, prepare a reasoned and learned rebuttal to submit to the editor. As a class, review, revise, and submit a response.

21. Given a science exam question, prepare a written or verbal explanation of the answer to a fellow student taking the course and to a student who has not taken the course.

22. Given a concept you are learning in another science course, write two paragraphs: one conveying that concept to a fellow student, and one conveying that concept to a grade # student.

23. Find a report or essay that you wrote at the last minute for another course. (That is, you started and finished it the night before it was due.) Review this report or essay.

24. Have students bring a complete laboratory report they have already submitted for marking. Have colleagues peer review the report. (Using a report they already submitted avoids any issues with a ... redacted in preview ...)
In-depth assignments

1. Create a résumé or curriculum vitae.
2. Prepare an email/letter to a professor asking about an advertised summer research opportunity.
3. Given a scholarly article, prepare a summary of the article.
4. Given a scholarly article, rewrite for a public audience with minimal loss of scientific accuracy.
5. Use additional resources to identify an accidental scientific discovery. Prepare a brief presentation on that discovery.
6. Figure 3.9 lists the levels of Bloom’s cognitive, affective, and psychomotor domains.
   a) For an assigned domain, prepare a presentation that defines each level and give example of a person at that level in a given career.
   b) For an assigned career, prepare a presentation on the traits a person in that career has at each level.
7. Prepare an investigative essay on ethics, professionalism, and plagiarism. (This can serve as a basis for discussions of these topics.)
8. Prepare a research proposal. Present this to a panel of fellow students. (Option: Dragon’s Den™ or Shark Tank™ concept)
9. Identify and investigate instances where private, corporate, or government results were skewed because of pressure to obtain the “preferred” results.
10. Select a scientist or graduate student researcher, interview them, and write a newspaper article about their career and achievements.
11. a) Paraphrasing Wikipedia or another reputable website, prepare a one-page biography of a historical science scholar. (Some... redacted in preview... )
13. Identify a faculty member preparing a document for publication.
   a) With permission of the author(s), review the document.
   b) Have the author(s) attend an open-feedback session. Have the course instructor facilitate how to properly give and receive feedback.

14. **Elevator pitch.** You are at a conference and meet a professor/senior executive from a group you really want to work with. In 90 seconds, explain to them your work, the quality thereof, and why they should hire you. This must be a focused *conversation*, not a *presentation*.

15. In a senior science course taken by students from multiple disciplines, have discipline specific groups that prepares a presentation on their (the group members) academic and employment interests. Peer review the presentation in class. Take these presentations to each first-year class. (This allows senior students to showcase their science, build presentation skills, and build comradery amongst students.)

16. Demonstrations are an excellent way to increase interest and engagement. Many reputable resources list demonstrations in all the sciences. Identify a demonstration that you would like to investigate. Prepare two versions of the demonstration:
   - a scientific version that explains the underlying science to your peers
   - a public version that explains the underlying science to the public

   (Hold a peer feedback session in class, then have a public presentation event. Invite the institution and local grade schools. Alternative or concurrently: film the demonstrations and put them online.)

... redacted in preview ...
Appendix C: Assignments

Term projects

For term projects, it is valuable to establish submission dates for project milestones, such as topic selection, project outline, annotated bibliography, and peer review events. The document should be complete, not draft, for all of the peer review events.

1. Adapt one of your laboratory reports into a scholarly poster, article, and/or presentation. *(Use different laboratory reports for each.)*

2. Prepare an investigative essay on
   a) a sustainability or environmental issue from the perspective of your discipline.
   b) a controversial scientific claim or possible pseudoscience claim.
   c) the science underlying a real-world application of science.
   d) a concept you are learning in another science course.

3. Prepare a scholarly poster for your essay from question 2, above.

4. With the permission of the laboratory coordinator, assign sections of the laboratory manual to groups of students. The groups edit the laboratory manual, consulting the laboratory coordinator as required. The instructor facilitates reviews by other student groups. With appropriate permissions, the revised experiments could be used in future editions of the laboratory manual!†

6. In consultation with the course instructor, select a scholarly publication at the beginning of the term. This article forms the basis for several assignments: a technical article (science news article), a non-technical article (newspaper article), a review article of progress since this particular article, a poster presentation, and an oral presentation, etc.

... redacted in preview ...
Appendix D: Assessment rubrics

Grading rubrics for laboratory reports, scholarly articles and essays, scholarly posters, and scientific presentations are given below.* There are three categories of criteria: content, organization, and presentation. These rubrics have a maximum of 30 points. Also included are a rubric for reviewing the members on your team (maximum 20 points) and for reviewing the reviewer (maximum 9 points).

About scholarly articles: the variability between disciplines makes it challenging to put together a rubric for grading a scholarly article. One option would be to enlist academic colleagues in the appropriate disciplines to evaluate student articles.

Engaging students

It may be challenging to engage students in meaningful peer-review and peer-evaluation — meaningful in that students put in the effort to accurately assess the work of their peers. The information on page 314 (Peer review in a classroom) sets the context for quality and effective peer review. Some students may want to give all their peers full marks. To address this, emphasize the following:

If every student gets an A, the grade is meaningless. Consider exams: while the grades range from 0 to 100 %, the average is typically between 60 and 80 %. For this project: you can assess any individual project from 0 to 100 % using the rubric, but your average must be between 60 and 80 %.

Some students may want to give all their peers the same grade. This penalizes those who did well and inflates the grades of those who put little effort into their project. Informing students why this is detrimental ...

... redacted in preview ...
<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presents too much information on the topic.</td>
<td>Presents insufficient information.</td>
<td>Is too short or superficial.</td>
</tr>
<tr>
<td>Most steps are easy-to-follow.</td>
<td>Some of the steps cannot be understood.</td>
<td>Procedure not consistent with experiment.</td>
</tr>
<tr>
<td>Some are unclear or lack detail.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data presentation could be improved. Some observations missing.</td>
<td>Extraneous data included, or no observations.</td>
<td>Incomplete or inaccurate.</td>
</tr>
<tr>
<td>Most calculations are correct and clearly presented, and include dimensional analysis.</td>
<td>Most calculations are correct and clearly presented. Dimensional analysis incorrect or absent.</td>
<td>Many calculations are incorrect or absent.</td>
</tr>
<tr>
<td>Theory properly applied to interpret data. Discussion similar to introduction.</td>
<td>Inconsistent application of theory to interpretation. Discussion suggests limited understanding.</td>
<td>Unclear and/or illogical.</td>
</tr>
<tr>
<td>Logical conclusions are drawn from the data. Impact to science and society are limited.</td>
<td>More conclusions could be drawn from the data.</td>
<td>Conclusions are not consistent with the data.</td>
</tr>
<tr>
<td>Minor lapses in clarity, concision, or readability.</td>
<td>Major lapses in clarity, concision, or readability.</td>
<td>One or more sections of the document are not understandable by the intended audience.</td>
</tr>
<tr>
<td>Figures and/or tables contain extraneous information.</td>
<td>Figures and/or tables are difficult to read.</td>
<td>Figures and/or tables are missing or contain inaccurate information.</td>
</tr>
<tr>
<td>A few deviations from the style guide.</td>
<td>Several deviations from the style guide. Inconsistent formatting.</td>
<td>Does not follow the style guide.</td>
</tr>
<tr>
<td>Several minor spelling or grammatical errors.</td>
<td>Spelling or grammatical errors affect the readability.</td>
<td>Poor aesthetic presentation.</td>
</tr>
<tr>
<td>A few minor spelling or grammatical errors.</td>
<td>Spelling or grammatical errors make sections unintelligible.</td>
<td></td>
</tr>
</tbody>
</table>

© Roy Jensen, 2014. Communicating Science
## Appendix D: Assessment Rubrics

<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presents too much information on the topic.</td>
<td>Presents insufficient information.</td>
<td>Is too short or superficial.</td>
</tr>
<tr>
<td>Information is in-depth, but strays into related topics.</td>
<td>Information covered superficially.</td>
<td>Topic is too broad and/or covered superficially.</td>
</tr>
<tr>
<td>All information is accurate, but occasionally superficial.</td>
<td>Some inaccurate and/or superficial information.</td>
<td>Significant inaccurate information.</td>
</tr>
<tr>
<td>Logical conclusions are drawn from the work. Impact to science and society are limited.</td>
<td>More conclusions could be drawn from the work.</td>
<td>Conclusions are not consistent with the work.</td>
</tr>
<tr>
<td>Minor lapses in clarity, concision, or readability.</td>
<td>Major lapses in clarity, concision, or readability.</td>
<td>Sections of the document are not understandable by the intended audience.</td>
</tr>
<tr>
<td>Figures and/or tables contain extraneous information.</td>
<td>Figures and/or tables are difficult to read.</td>
<td>Figures and/or tables are missing or contain inaccurate information.</td>
</tr>
<tr>
<td>A different order would better present the information.</td>
<td>Some discontinuity between topics.</td>
<td>Poor continuity between topics.</td>
</tr>
<tr>
<td>Information is mostly from reputable sources.</td>
<td>Extra citations are included.</td>
<td>Sources are questionable and/or citations are missing.</td>
</tr>
<tr>
<td>A few deviations from the style guide.</td>
<td>Several deviations from the style guide. Inconsistent formatting.</td>
<td>Does not follow the style guide. Poor aesthetic presentation.</td>
</tr>
<tr>
<td>A few minor spelling or grammatical errors.</td>
<td>Spelling or grammatical errors affect the readability.</td>
<td>Spelling or grammatical errors make one or more sections unintelligible.</td>
</tr>
</tbody>
</table>

© Roy Jensen, 2014. *Communicating Science*
<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>Introduction fails to rationalize project. Information covered superficially.</td>
<td>Topic is too broad and/or covered superficially.</td>
</tr>
<tr>
<td>All information is accurate, but occasionally superficial.</td>
<td>Some inaccurate and/or superficial information.</td>
<td>Significant inaccurate information.</td>
</tr>
<tr>
<td>Logical conclusions are drawn from the data. Impact to science and society are limited.</td>
<td>More conclusions could be drawn from the data.</td>
<td>Conclusions are not consistent with the data.</td>
</tr>
<tr>
<td>Minor lapses in clarity, concision, or readability.</td>
<td>Major lapses in clarity, concision, or readability.</td>
<td>Sections of the document are not understandable by the intended audience.</td>
</tr>
<tr>
<td>Figures and/or tables contain extraneous information.</td>
<td>Figures and/or tables are difficult to read.</td>
<td>Figures and/or tables are missing or contain inaccurate information.</td>
</tr>
<tr>
<td>A different order would better present the information.</td>
<td>Some discontinuity between topics.</td>
<td>Poor continuity between topics.</td>
</tr>
<tr>
<td>Information is mostly from reputable sources.</td>
<td>Extra citations are included.</td>
<td>Sources are questionable and/or citations are missing.</td>
</tr>
<tr>
<td>Pleasant appearance. Text in figures and/or tables difficult to read.</td>
<td>Looks messy. Some sections difficult to read.</td>
<td>Looks busy. Difficult to follow and read.</td>
</tr>
<tr>
<td>A few minor spelling or grammatical errors.</td>
<td>Spelling or grammatical errors affect the readability.</td>
<td>Spelling or grammatical errors make sections unintelligible.</td>
</tr>
<tr>
<td>Presenter lacks confidence, but understands work.</td>
<td>Presenter has limited understanding of work.</td>
<td>Presentation memorized or read. Poor pronunciation, poor projection, minimal eye contact.</td>
</tr>
</tbody>
</table>

© Roy Jensen, 2014. Communicating Science
## Appendix D: Assessment rubrics

<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oral presentation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good—</td>
<td>Poor—</td>
<td>Unsatisfactory</td>
</tr>
<tr>
<td>Introduction is concise and engaging. Information is in-depth, but strays into related topics.</td>
<td>Introduction fails to rationalize work. Information covered superficially.</td>
<td>Topic is too broad and/or covered superficially.</td>
</tr>
<tr>
<td>All information is accurate, but occasionally superficial.</td>
<td>Some inaccurate and/or superficial information.</td>
<td>Significant inaccurate information.</td>
</tr>
<tr>
<td>Logical conclusions are drawn from the data. Impact to science and society are limited.</td>
<td>More conclusions could be drawn from the data.</td>
<td>Conclusions are not consistent with the data.</td>
</tr>
<tr>
<td>Figures and/or tables contain extraneous information.</td>
<td>Figures and/or tables are difficult to read.</td>
<td>Figures and/or tables are missing or contain inaccurate information.</td>
</tr>
<tr>
<td>A different order would better present the information.</td>
<td>Some discontinuity between topics.</td>
<td>Poor continuity between topics.</td>
</tr>
<tr>
<td>Structured layout, but appears cluttered or busy.</td>
<td>Hard to read because of font, color, or layout.</td>
<td>Few headings, poor organization. Too much information per slide.</td>
</tr>
<tr>
<td>Information is mostly from reputable sources.</td>
<td>Extra citations are included.</td>
<td>Sources are questionable and/or citations are missing.</td>
</tr>
<tr>
<td>Multimedia is focused on-topic.</td>
<td>Some multimedia is not relevant to the topic or animations detract from presentation.</td>
<td>Multimedia is lengthy and/or detracts from topic.</td>
</tr>
<tr>
<td>Presenter lacks confidence, but makes attempts to project voice and make eye contact.</td>
<td>Presenter adds little additional information than what is on slide.</td>
<td>Presentation memorized or read. Poor pronunciation, poor projection, minimal eye contact.</td>
</tr>
<tr>
<td>Answers questions by repeating presentation material.</td>
<td>Hesitantly answers questions. Uncertain about material.</td>
<td>Superficial answers, or doesn’t answer questions.</td>
</tr>
</tbody>
</table>

© Roy Jensen, 2014. Communicating Science
<table>
<thead>
<tr>
<th>Good</th>
<th>Un satisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completes a fair share of the team’s work with acceptable quality.</td>
<td>Does not do a fair share of the team’s work.</td>
</tr>
<tr>
<td>Keeps commitments and completes assignments on time.</td>
<td>Delivers sloppy or incomplete work.</td>
</tr>
<tr>
<td>Helps teammates who are having difficulty when it is easy or important.</td>
<td>Misses deadlines. Is late, unprepared, or absent from team meetings.</td>
</tr>
<tr>
<td>Encourages the team to do good work that meets all requirements.</td>
<td>Does not assist teammates. Quits if the work becomes difficult.</td>
</tr>
<tr>
<td>Wants the team to perform well enough to earn all available rewards.</td>
<td>Satisfied, even if the team does not meet assigned standards.</td>
</tr>
<tr>
<td>Believes that the team can meet all of its responsibilities.</td>
<td>Wants the team to avoid work, even if it hurts the team.</td>
</tr>
<tr>
<td>Demonstrates sufficient knowledge, skills, and abilities to contribute to the team’s work.</td>
<td>Doubts that the team can meet its requirements.</td>
</tr>
<tr>
<td>Acquires knowledge or skills as needed to meet requirements.</td>
<td>Missing basic qualifications needed to be a member of the team.</td>
</tr>
<tr>
<td>Can perform some of the tasks normally done by other teammates.</td>
<td>Unable or unwilling to develop knowledge and skills to contribute to the team.</td>
</tr>
<tr>
<td>Listens to teammates and respects their contributions.</td>
<td>Unable to perform any of the duties of other team members.</td>
</tr>
<tr>
<td>Communicates clearly. Shares information with teammates.</td>
<td>Interrupts, ignores, or ridicules teammates.</td>
</tr>
<tr>
<td>Respects and responds to feedback from teammates.</td>
<td>Takes actions that affect teammates without their input. Does not share information.</td>
</tr>
<tr>
<td>Notices changes in dynamics that affect team progress.</td>
<td>Is defensive. Will not accept help or advice from teammates.</td>
</tr>
<tr>
<td>Knows what teammates should be doing and identifies problems.</td>
<td>Is unaware of team progress.</td>
</tr>
<tr>
<td>Alerts the team to possible problems that may affect the team success.</td>
<td>Does not pay attention to the progress of their teammates.</td>
</tr>
<tr>
<td>Demonstrates behaviors described in both Good and Good.</td>
<td>Avoids discussing obvious team problems.</td>
</tr>
</tbody>
</table>

adapted from a rubric by Dr. Matthew Ohland, et al., Engineering, Purdue University
<table>
<thead>
<tr>
<th>Good</th>
<th>Poor</th>
<th>Unsatisfactory</th>
</tr>
</thead>
<tbody>
<tr>
<td>The reviewer provided minimal feedback on some sections of the document.</td>
<td>The reviewer provided no feedback on some sections of the document.</td>
<td>The reviewer provided no feedback on major sections (more than half) of the document.</td>
</tr>
<tr>
<td>The reviewer identified most areas that required major and minor improvement.</td>
<td>The reviewer identified most areas that required major improvement.</td>
<td>The reviewer missed sections that obviously required improvement.</td>
</tr>
<tr>
<td>The reviewer’s feedback was mostly constructive with a few negative statements.</td>
<td>The reviewer’s feedback was a mix of constructive and negative statements.</td>
<td>The reviewer’s comments were negative or the reviewer provided little useful feedback.</td>
</tr>
</tbody>
</table>
### PRESENTATION

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The presentation is focused and on-topic.</td>
</tr>
<tr>
<td>2</td>
<td>The presentation is at an appropriate scientific level.</td>
</tr>
<tr>
<td>3</td>
<td>The material is presented in a way that facilitates learning. (logical progression, appropriate instructional strategies)</td>
</tr>
<tr>
<td>4</td>
<td>The slides contain a mix of text and images that stay on topic. (appropriately sized text and images, headings and captions appropriate)</td>
</tr>
<tr>
<td>5</td>
<td>The presentation cites appropriate scientific sources.</td>
</tr>
<tr>
<td>1</td>
<td>The speakers are audible and convey enthusiasm about the topic.</td>
</tr>
<tr>
<td>2</td>
<td>The speakers are knowledgeable about the material. (didn’t read script, correct pronunciation, have greater knowledge than is presented)</td>
</tr>
<tr>
<td>3</td>
<td>The presentation is reasonably paced and flows smoothly. (practiced and of professional quality)</td>
</tr>
<tr>
<td>4</td>
<td>Questions are answered professionally.</td>
</tr>
<tr>
<td>5</td>
<td>Overall, the presentation is interesting and informative.</td>
</tr>
</tbody>
</table>

Points: \[ \quad \] /50

### POSTER

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The poster is focused and on-topic.</td>
</tr>
<tr>
<td>2</td>
<td>The poster content is at an appropriate scientific level.</td>
</tr>
<tr>
<td>3</td>
<td>The poster is accurate and presented in a way that facilitates learning. (short statements, bulleted points, graphics)</td>
</tr>
<tr>
<td>4</td>
<td>The poster layout is logical and easy to follow. (short introduction, results and discussion, short summary/conclusion)</td>
</tr>
<tr>
<td>5</td>
<td>The poster contains a mix of text and images that stay on topic. (appropriately sized text and images, headings and captions appropriate)</td>
</tr>
<tr>
<td>1</td>
<td>The poster cites appropriate scientific sources.</td>
</tr>
<tr>
<td>2</td>
<td>The speakers are audible and convey enthusiasm about the topic.</td>
</tr>
<tr>
<td>3</td>
<td>The speakers are knowledgeable about the material. (didn’t read script, correct pronunciation, have more knowledge than on poster)</td>
</tr>
<tr>
<td>4</td>
<td>The presentation is reasonably paced and flows smoothly. (practiced and of professional quality)</td>
</tr>
<tr>
<td>5</td>
<td>Questions are answered professionally.</td>
</tr>
</tbody>
</table>

Points: \[ \quad \] /50
## Index

<table>
<thead>
<tr>
<th>— A —</th>
<th>— C —</th>
</tr>
</thead>
<tbody>
<tr>
<td>abbreviations</td>
<td>cartesian coordinates</td>
</tr>
<tr>
<td>academic integrity</td>
<td>Chicago style</td>
</tr>
<tr>
<td>academic work</td>
<td>citing multimedia</td>
</tr>
<tr>
<td>acronyms</td>
<td>citation</td>
</tr>
<tr>
<td>ACS style</td>
<td>citing online and database articles</td>
</tr>
<tr>
<td>active learner</td>
<td>formatting examples</td>
</tr>
<tr>
<td>active voice</td>
<td>in text alphabetical formatting</td>
</tr>
<tr>
<td>converting to</td>
<td>in text numerical formatting</td>
</tr>
<tr>
<td>addresses</td>
<td>other citation formats</td>
</tr>
<tr>
<td>adverbs</td>
<td>using material without permission</td>
</tr>
<tr>
<td>AIP style</td>
<td>citation-sequence citation format</td>
</tr>
<tr>
<td>alphabetical citation format</td>
<td></td>
</tr>
<tr>
<td>alternate hypothesis</td>
<td>citation</td>
</tr>
<tr>
<td>see citation</td>
<td>clarity</td>
</tr>
<tr>
<td>AMA style</td>
<td>colchés</td>
</tr>
<tr>
<td>ambiguous pronouns</td>
<td>coherence</td>
</tr>
<tr>
<td>analogy</td>
<td>collaborative research</td>
</tr>
<tr>
<td>annotated bibliography</td>
<td>competitive research</td>
</tr>
<tr>
<td>annotation</td>
<td>concept mapping</td>
</tr>
<tr>
<td>by hand</td>
<td>concept validation</td>
</tr>
<tr>
<td>pdf files</td>
<td>construct validity</td>
</tr>
<tr>
<td>Word files</td>
<td>constructivist theory</td>
</tr>
<tr>
<td>anomalous data</td>
<td>contractions</td>
</tr>
<tr>
<td>ANOVA</td>
<td>copyright</td>
</tr>
<tr>
<td>answering questions</td>
<td>cover letter</td>
</tr>
<tr>
<td>anthropology</td>
<td>creating a graph</td>
</tr>
<tr>
<td>APA style</td>
<td>credentials</td>
</tr>
<tr>
<td>apostrophe</td>
<td>CSE style</td>
</tr>
<tr>
<td>applied research</td>
<td>curriculum vitae</td>
</tr>
<tr>
<td>applied science</td>
<td>232, 236–38</td>
</tr>
<tr>
<td>article</td>
<td>223, 226</td>
</tr>
<tr>
<td>article summary</td>
<td>292</td>
</tr>
<tr>
<td>asking questions</td>
<td>aspect</td>
</tr>
<tr>
<td>assessment rubrics</td>
<td>26</td>
</tr>
<tr>
<td>assignments</td>
<td>367</td>
</tr>
<tr>
<td>average, calculation thereof</td>
<td>361</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>— B —</th>
<th>— D —</th>
</tr>
</thead>
<tbody>
<tr>
<td>basic research</td>
<td>brackets (punctuation)</td>
</tr>
<tr>
<td>blogs</td>
<td>brainstorming</td>
</tr>
<tr>
<td>Bloom’s taxonomy</td>
<td>British vs. American English</td>
</tr>
<tr>
<td>306</td>
<td>38</td>
</tr>
<tr>
<td>134</td>
<td>71, 73</td>
</tr>
<tr>
<td>16</td>
<td>87</td>
</tr>
<tr>
<td>213</td>
<td>45</td>
</tr>
<tr>
<td>95</td>
<td>14</td>
</tr>
<tr>
<td>40</td>
<td>154</td>
</tr>
<tr>
<td>20</td>
<td>305</td>
</tr>
<tr>
<td>96</td>
<td>63</td>
</tr>
<tr>
<td>304</td>
<td>76</td>
</tr>
</tbody>
</table>

brackets (punctuation) | 16 |
brainstorming | 213 |
British vs. American English | 40 |
b bulleted list | 38 |
| 179 | 39 |
| 3, 200 | 76 |
| 137 | 76 |
| 27 | 76 |
| 29 | 76 |
| 64 | 85 |
| 51 | .86 |
| 34 | .80 |
| 223 | .78 |
| 316 | .79 |
| 357 | .86 |
| 358 | .87 |
| 109 | .13 |
| 115 | .71, 73 |
| 292 | .45 |
| 52 | .232 |
| 76 | .194 |
| 15 | .10 |
| 169 | .20 |
| 167 | .154 |
| 232, 236–38 | .2 |
| 223, 226 | .112 |
| 292 | .178 |
| 26 | .121 |
| 367 | .44 |
| 361 | .71 |
| average, calculation thereof | .96 |
| 110 | .63 |
| 134 | .304 |
— D —
dash (punctuation) ........................................ 17
data (singular or plural)................................. 37
date and time.................................................. 62
deduction ...................................................... 164
degrees of freedom ........................................ 111
deviating from the guidelines ............................. 12
dissertation ..................................................... 232
distracting mannerisms ..................................... 289
divisions of science .......................................... 167
document development
preparation .................................................. 202
revision ....................................................... 204
submission ................................................... 205
document formatting ......................................... 206
document grammar
aspect ................................................................ 26
mood .................................................................. 26
tense .................................................................. 26
document language .............................................. 25
British vs. American English ............................. 40
Latin phrases ................................................... 41
lists .................................................................... 38
nominalization .................................................. 32
parallel structure ............................................. 37
subject-verb agreement .................................... 36, 9
tense .................................................................. 27
voice .................................................................. 27
document readability .......................................... 207
document structure ............................................ 20
paragraph .......................................................... 22
section ............................................................. 24
sentence ........................................................... 20
documents for other audiences ............................ 264
double negatives ............................................... 52

— E —
editing .................................................................. 315
annotating pdf files .......................................... 357
annotating Word files ..................................... 358
electronic annotation ........................................ 357
notation ............................................................. 316
effective learning and studying strategies ................. 155
effective presentations ....................................... 286
electronic annotation ........................................... see annotation
ellipses (punctuation) ......................................... 17
em dash ............................................................. 17
email ................................................................. 297, 300
signature ........................................................... 300
engaged learner ............................................... 300
Equation Editor .................................................. 137
eyes ................................................................. 232, 242–44
evolution of science ........................................... 162
Excel
creating graphs .................................................. 348
formatting cells ............................................... 342
formulae ........................................................... 345
page setup ....................................................... 342
pasting into other documents ............................. 351
Solver ............................................................... 347
exclamation mark ............................................... 16
experimental labels .......................................... 70
external validity ................................................. 178

— F —
face validity ...................................................... 178
feedback ........................................................... 320
field codes ......................................................... 333
figure .................................................................. 91
colorizing ........................................................... 92
first person ......................................................... 30
flowcharts ......................................................... 154
fonts
formatting .......................................................... 18
other characters ................................................. 18, 333
STIX fonts .......................................................... 18
formal science .................................................... 167
formatting
addresses ........................................................... 64
capitalization ...................................................... 61
credentials and titles ......................................... 63
date and time ...................................................... 62
experimental labels .......................................... 70
mathematical equations ....................................... 65, 68, 69
numbers ............................................................. 66
phone numbers ................................................... 63
plural symbols and numbers ............................. 69
uncertainty .......................................................... 67
units ................................................................. 67

formatting scientific information ......................... see formatting
forums ............................................................. 306
freewriting ......................................................... 213
fundamental research research ............................ 169
Index 377

— G —
gender neutrality .................................. 49
ghostwriting ..................................... 73
grammatical aspect ............................ 26
grammatical mood .............................. 26
grammatical tense ............................. 26
graph ............................................... 91, 95
  3D graph ...................................... 106
  axis labels .................................... 98
  bar graph .................................... 104
  hand drawn ................................... 99
  labelling ....................................... 96
  pie chart ..................................... 106
  plotting multiple data sets ............ 100
  plotting non-linear data ............... 102
  scatter plot .................................. 103
Greek characters .............................. 18

— H —
Harvard citation format............ see citation
Harvard formatting ....................... 77
history of science ......................... 162
  modern science .......................... 165
  scientific revolution .................... 163
hyphen ......................................... 17
hypothesis ..................................... 171
  null and alternate ....................... 108

— I —
idioms ........................................... 53
IEEE style ...................................... 76
image ........................................... 91, 93
imprecise words ............................ 57
induction ...................................... 164
internal validity ............................ 178
investigative project
  conducting .................................. 182

— J —
James Zull ..................................... 127
jargon .......................................... 42
journalistic method ...................... 214

— K —
keyboard shortcuts
  Excel .......................................... 342
  PowerPoint .................................. 352
  Word .......................................... 328
knowledge .................................... 119
  Kolb learning model ..................... 127

— L —
laboratory notebook ..................... 209, 212
laboratory report ......................... 216, 219–22
  complete vs. summary report ......... 216
language level ................................ 43
Latin phrases .................................. 41
Latin words .................................... 37
law .............................................. 171
learning ....................................... 119, 129
  biophysical processes ................. 119, 129
  Bloom’s taxonomy ....................... 134
  concept mapping ......................... 154
  constructivist theory .................... 121
  effective strategies ..................... 134
  flowcharts .................................. 154
  learner stages ............................. 137
  learning theories ......................... 121
  optimizing instruction .................. 145
  optimizing learning ...................... 140
  reading for understanding .......... 148
  self-determination theory ............ 122
  self-regulated learning ............... 124
  working and long-term memories ... 133
letter ........................................... 297, 298
level of statistical significance ....... 115
life science .................................. 167
lists .......................................... 38
literary work ............................... 3, 200
literature review ............................ 190
  source credibility ....................... 192
  sources ..................................... 191
logical progression ...................... 11
long-term memory .......................... 133
— M —
mapping .................. see storyboarding
mass vs. weight .................. 70
mathematical equations (formatting) .... 65, 68, 69
maximizing exam grades .......... 157
media inquiries .................. 306
meeting .................. 304
memo .......................... 297, 298
metaphor .................. 34
method validity .................. 178
misplaced modifier .............. 50
MLA style .......................... 76
modern science .............. 165
mood .................................. 26
multimedia .................. 85
multiple adjectives .............. 51

— N —
name-year citation format ... see citation
nervousness .................. 290
neuron development (learning) .... 126
nominalization .............. 32
non-copyrightable information ...... 74
nonrestrictive clauses .......... 21
null hypothesis .............. 108
numbers (formatting) ........ 66
numeric citation format ........ see citation

— O —
object (in sentence) .............. 20
observations .................. 170
optimizing instruction ........ 145
optimizing learning ........ 140
oral presentation .......... see presentation
other audiences .................. 264
outlining .................. see storyboarding

— P —
paragraph .................. 22
parallel structure .............. 37
paraphrasing .................. 73
parentheses .................. 16
passive learner .................. 137
passive voice .................. 27
peer evaluation .................. 311, 323
peer review .................. 311, 312
inging .................. 315
period (punctuation) ........ 14
person .................. 30
phone call .................. 304
phone numbers .................. 63
physical science .............. 167
plagiarism .............. 72
pleonasms .............. 56
plotting data .................. 96
plural symbols and numbers .... 69
poster .................. 251, 256–57
headings .................. 254
layout .................. 252
presenting .................. 258
reviewing .................. 260
sample posters .............. 261
poster session .................. 255
PowerPoint
creating a poster .............. 354
slide master .................. 352
precision .................. 2
predicate .................. 20
preparing for questions .......... 291
presentation .............. 268, 273–82
slides .................. 271
software .................. 270
storytelling .................. 283
team presentation .............. 271
prewriting .................. 213
product-directed research ........ 169
progress report .......... 216, 217, 222
project report .................. 218
propagation of uncertainty .... 116
proposal .............. 227, 229–31
public copyright license ....... 75
public speaking .............. 286
answering questions ............ 292
asking questions ............ 292
distracting mannerisms ........ 289
nervousness .............. 290
preparing for questions .......... 291
publications, types of ........ 199, 232
punctuation .............. 13–17
— Q —

Q-test ........................................ 109
question mark.............................. 15
questions
    answering questions .................. 292
    asking questions .................... 292
    preparing for ........................ 291
quotation marks ........................ 15

— R —

readability statistics .................. 207
reading for understanding ............ 148
reporters .................................. 306
reporting statistical information..... 111
research
    academic integrity .................. 179
    document development ............. 201
    literature review .................... 190
    realities of .......................... 193
    research ethics ....................... 180
    research question .................... 187
    types of ................................ 169
research and development ............ 169
research article ....................... see article
research funding ....................... 227
research methodology ................. 161
research methods ....................... 170
    validity ................................ 178
research project
    conducting ............................ 184
research proposal ...................... see proposal
research question ...................... 187
restrictive clauses ..................... 21
résumé .................................. 304
review article .......................... 232
review questions ........................ 325
review, self ............................. 203
revision .................................. 42, 204
    abbreviations ....................... 39
    acronyms ................................ 39
    ambiguous pronouns ................. 51
    anthropomorphism ................... 52
    circumlocution ...................... 55
    clichés ................................ 53
    commonly confused words .......... 45
    contractions ......................... 44
    double negatives .................... 52
    gender neutrality .................... 49
    idioms ................................ 53
    imprecise words ..................... 57
    jargon ................................ 42
    language level ........................ 43
    Latin words .......................... 37
    misplaced modifier .................. 50
    multiple adjectives ................. 51
    multiple adverbs .................... 51
    pleonasms ............................ 56
    scientific terms ..................... 25
    tautology ................................ 54
    vague words .......................... 57
Roman characters ...................... 18

— S —

scholarly article ...................... see article
scholarly poster ....................... see poster
scholarships ................................ 228
science
    divisions ................................ 167
    science disciplines ................ 167
    scientific figure ..................... see figure
    scientific law ........................ 171
    scientific method .................... 186
    scientific misconduct .............. 31
    scientific revolution .............. 163
    scientific tables .................... 88
    scientific terms ..................... 25
    scientific writing .................. 8, 10
search engines ........................ 192
second person ........................... 30
section (document structure) ......... 24
self-determination theory .......... 122
self-directed learner ................. 137
self-regulated learning .............. 124
semicolon ................................ 14
sentence ................................ 20
    types of ................................ 21
simile ................................... 34
social science ......................... 167
software ................................ 327
    editing ................................ 357
    equation editor ........................ 356
    presentation ............................ 270, 352
    spreadsheet .......................... 342
    word processing ..................... 328
spelling and grammar analysis ....... 207
split infinitives ......................... 36
standard deviation ..................... 111
statistical analysis ..................... 108
ANOVA .................................... 115
average .................................... 110
confidence interval .................... 112
degrees of freedom ..................... 111
level of statistical significance ...... 115
propagation of uncertainty .......... 116
Q-test ....................................... 109
reporting ................................... 111
standard deviation ..................... 111
statistical validity ...................... 178
STIX fonts .................................. 18
storyboarding ............................. 213
stress position ......................... 11, 22
subject-verb agreement .............. 36, 9
submission ................................ 205
Symbol characters ...................... 18

— T —
tables ....................................... 88
tautology .................................... 54
teaching dossier ......................... 305
tense ......................................... 26, 27
theory ....................................... 171
thesis ....................................... 232, 245–50
thesis statement ......................... 188
third person ................................ 30
titles .......................................... 63
tone ............................................ 5
topic position ............................ 11, 22
topic sentence ......................... 22
transition words ....................... 23

— U —
uncertainty (formatting) ............. 67
undergraduate laboratory courses .. 196
units (formatting) ...................... 67

— V —
vague words .............................. 57
Vancouver formatting ................. 77
verb .......................................... 20
video call .................................. 304
voice ......................................... 27

— W —
weight vs. mass ......................... 70
white space .............................. 207
Wikipedia ................................ 192

Word
autocorrect ............................. 339
autonumbering .......................... 335
background .............................. 339
fields ....................................... 333
footnotes .................................. 337
formatting characters ............... 328
headers and footers .................. 334
page setup ............................... 329
sections .................................... 330
spelling and grammar analysis .... 338
styles ....................................... 330
table of .................................... 336
templates .................................. 341
views ....................................... 328
work (re copyright) .................... 71
writing for the reader ............... 133
## Editing and formatting notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>Text with error</th>
</tr>
</thead>
<tbody>
<tr>
<td>^</td>
<td>insert indicated</td>
<td>In February 2009, experiments testing the validity of Thomas model were</td>
</tr>
<tr>
<td></td>
<td>punctuation or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>text.</td>
<td></td>
</tr>
<tr>
<td>#</td>
<td>insert space</td>
<td>sodium emission at 589.3 nm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>insert period</td>
<td>travelling at 100 km/hr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>insert en dash</td>
<td>melting point of 155–157 °C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>insert em dash</td>
<td>Sample 3, which should have the laser was used to ionize the sample</td>
</tr>
<tr>
<td></td>
<td></td>
<td>an angle of 125 °</td>
</tr>
<tr>
<td></td>
<td>delete text</td>
<td>live either in freshwater or in saltwater</td>
</tr>
<tr>
<td></td>
<td>close up spacing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>transpose</td>
<td></td>
</tr>
<tr>
<td></td>
<td>move to indicated</td>
<td>In case of fire, pull the fire alarm (immediately)</td>
</tr>
<tr>
<td></td>
<td>location</td>
<td></td>
</tr>
<tr>
<td></td>
<td>start a new paragraph</td>
<td>accurate under ambient conditions. The compressibility, ( Z ), measures the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>use 250 mL beakers</td>
</tr>
<tr>
<td></td>
<td>write out or abbreviate</td>
<td>confirmed a negative reaction enthalpy</td>
</tr>
<tr>
<td></td>
<td>let it stand (ignore</td>
<td></td>
</tr>
<tr>
<td></td>
<td>suggestions)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>make lowercase</td>
<td>0.10 mol/L Hydrochloric Acid</td>
</tr>
<tr>
<td></td>
<td>make uppercase</td>
<td>The large hadron collider in Europe</td>
</tr>
<tr>
<td></td>
<td>make small caps</td>
<td>the molarity (M) of a solution</td>
</tr>
<tr>
<td></td>
<td>make <strong>boldface</strong></td>
<td>let N be a 2 ( \times ) 2 matrix</td>
</tr>
<tr>
<td></td>
<td>make <em>italics</em></td>
<td>( E = m c^2 )</td>
</tr>
<tr>
<td></td>
<td>make roman</td>
<td>The largest change was observed</td>
</tr>
<tr>
<td></td>
<td>wrong font</td>
<td>The largest change was observed</td>
</tr>
<tr>
<td></td>
<td>change font size</td>
<td>The largest change was observed</td>
</tr>
<tr>
<td></td>
<td>move left/right</td>
<td>( F = m a )</td>
</tr>
<tr>
<td></td>
<td>raise/lower</td>
<td>( C_1 P_1 = C_2 V_2 )</td>
</tr>
<tr>
<td></td>
<td>center</td>
<td>The End</td>
</tr>
<tr>
<td></td>
<td>align</td>
<td>Hydrothermal vents on the ocean floor support an abundance of life.</td>
</tr>
<tr>
<td></td>
<td>superscript</td>
<td>3.00 ( \cdot ) 10^8 m/s</td>
</tr>
<tr>
<td></td>
<td>subscript</td>
<td>0.25 mol/L CH(_3)COOH</td>
</tr>
</tbody>
</table>
Communicating Science provides undergraduate science and engineering students and new technical writers with a foundation for writing, reviewing, and presenting scientific information: reports, proposals, scholarly articles, essays, theses, scholarly posters, oral presentations, and documents for public audiences.