This publication was prepared by the staff and Peer Helpers of the Learning Commons.
About our cover:

When the University of Guelph was incorporated in 1964, the institution adopted the name and some of the history of the City of Guelph. Guelph’s name comes from “Welfen,” the family name of the royal House of Hanover. That ancestry is recognized by the white Hanovarian stallion which appears on the University of Guelph’s official crest and in this 1981 painting by Heather Cooper. The original painting still hangs in the University Library, depicting the Hanovarian stallion with the winged horse, Pegasus, the symbol of poetic inspiration.
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Making a “Science” of Scientific Writing

Make Your Writing Familiar to Your Reader

Keep Subjects Close to Their Verbs

Emphasize Important Information

Set a Context for the Important Information

Focus Your Sentence Action

Grammar and Scientific Style

Use of First Person (I, We)

Use of the Passive Voice

Avoid “Creative” Language and “Value Judgements”

Recognise Shifts in Verb Tense

Make Your Writing Concise, Precise and Simple

Common Writing Faults

The Sentence Fragment

Conjunctions

The “However-Semicolon” Disease and Conjunctive Adverbs

Keeping Verbs as Verbs

The Revision Process

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Appendix 1

Lab Report Revision Checklist


Introduction

Surely the scientist, of all people, is under the obligation to write not only so that he may be understood, but so that he cannot be misunderstood.

E.H. McClelland (1943)

It might be reasonable to assume that if you are a science student you will not have to do a lot of writing in your university science courses. Essays and book reviews for English literature, position papers for political science or history, and expositions of philosophical arguments are expected in the arts. In contrast, in biology, chemistry, physics and mathematics, scientists carry out experiments, analyze data, make calculations, design computer software, and account for and explain technological and natural phenomena. So you may think that writing is not important in the sciences.

However, writing is not restricted to the arts and humanities. Language and writing are used by scientists and science students to communicate their findings and explain their research results: it is necessary to convert collected data into sentences. Having worked hard on the scientific and technical details of their research, scientists must then work hard on producing words to explain that research clearly and efficiently to others so their research “cannot be misunderstood.” For example, a biologist might need to express the results of an experiment in which *Dictyostelium discoideum* was essential in learning that
cytoskeletal proteins have overlapping functions and an engineer the feasibility of building a special computer to monitor cardiac output by non-invasive means.

In addition, scientists frequently write to explain or debate the ideas and writing of other scientists, as well as writing science for non-experts in more “popular” and general-interest publications such as Canadian Geographic, Time, Sierra Club Green Guide, Popular Mechanics, or the local newspaper. In fact, according to statistics at San Diego State University, careers in technical and scientific communication are among the top ten fastest growing fields in the United States.

When asked to rank skills that a biologist must possess, biotech companies place effective communication second only to relevant work experience and ahead of other factors such as science background, grade-point average and references. It is fitting, therefore, that Robert Barass (1991) entitled his book Scientists Must Write: A Guide to Better Writing for Scientists, Engineers, and Students.

And science writing has been steadily increasing: the editor of one scientific journal notes that scientific articles submitted for publication to his journal have increased in page length from an average of 5.4 pages in 1989 to 6.5 pages in 1997 (Harris, 1998). As noted by this editor, and in all of the cases above, it is apparent that scientists must write clearly, briefly and simply.

The Purpose of Scientific Writing

All writing has a purpose or purposes — to inform, to entertain, to persuade, to inspire, to justify, to instruct. While essays generally do many of these things at once, scientific papers
are primarily intended to inform. Scientists depend on written scientific communications to keep up with what is happening in their field and to communicate research results to others.

Science investigates natural phenomena and attempts to understand and systematize them by observing events and testing hypotheses created to explain them. The research process begins with a question — an hypothesis — around which an experiment is designed. The experiment is not intended to “prove” an hypothesis but to test it to determine the extent to which the results support that hypothesis. Sometimes, the results of the experiment do not support the claims of the hypothesis; “ruling out” an hypothesis is an important stage in discovering the true nature of phenomena. Only when the experiment can be duplicated and when best efforts fail, time after time, to disprove the hypothesis, can the hypothesis be said to be supportable and the results “true.”

The scientific method determines what is considered important in scientific writing. Effective research based on this method avoids vague hypotheses and unfocused data collection; in the same way, effective scientific writing conveys information in a clear, accurate and organized way.

**Content and Form**

Although you cannot realistically separate content and form in scientific writing, sometimes it is useful to think of the writing process as having these two basic components — both must be given due consideration.
Scientists and science students perform their day-to-day business in physical, tangible ways: through observation and measurement; they perform experiments, design research trials, and analyze data. However, what they learn or discover, and what actions they take (or recommend be taken), are usually communicated in written form.

Michael Alley, a scientist and researcher of scientific writing, breaks down writing and language to an even greater degree:

In writing, language is the way that words are used. Language is word choice, the arrangement of phrases, the structuring of sentences and paragraphs, and more. In scientific writing, language includes the use of numbers, equations, and abbreviations; it includes the use of examples and analogies (1987, p 25).

So, on one hand, assume that science is communicated via language and that we cannot think of content and form as discrete, separable units; on the other hand, however, it is always useful to divide and conquer any writing task that lies ahead of you: think both about the “content” of your writing and the “form” it will take.
The Research Article

As an undergraduate science student, there is one organizational structure with which you should become familiar, the one that is most commonly used in scientific disciplines to report experimental research. The research article is divided into sections that parallel the experimental process.

This structure is called IMRAD (Introduction, Methods, Results and Discussion). The different sections allow readers to quickly identify what they are looking for and to follow, in a logical manner, the work done by the author.

Your undergraduate writing assignments may include lab reports, literature reviews, journal article critiques, poster presentations and abstracts. To complete these assignments successfully, you must have a good understanding of the purpose, structure and content of research articles.

The table following outlines the type of information scientific readers will expect to find in each section of the research article.
<table>
<thead>
<tr>
<th>IMRAD Structure for Scientific Research Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
</tr>
<tr>
<td>The Title is not a section but it is important as it is often the first thing read. It should indicate the topic of the research and provide key words for indexing.</td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
</tr>
<tr>
<td>The Abstract is a clear, concise summary of the entire paper. It should include the question(s) investigated, the experimental design and methods used, the major findings, and most importantly, a statement of conclusions.</td>
</tr>
<tr>
<td><strong>Introduction</strong></td>
</tr>
<tr>
<td>The Introduction provides the rationale for the experiment. It describes the problem to be investigated, providing the context, key terms and concepts so that the experiment can be understood. It also reviews the relevant research to provide a rationale for the experiment — what findings of others are being challenged or extended. It then outlines the hypotheses and research questions.</td>
</tr>
<tr>
<td><strong>Materials &amp; Methods</strong></td>
</tr>
<tr>
<td>The Methods section describes the steps followed in conducting the research and the materials used at each step. It is not only useful to readers who want to know what methods were used and how this may have influenced the results, but also to those who are interested in replicating and reproducing the study. Consequently, it should be sufficiently detailed to allow them to do so.</td>
</tr>
<tr>
<td>Results</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>The Results section should present only results which relate back to the question posed in the Introduction (the hypothesis). It functions as a stepping stone to the Discussion section by presenting the framework on which the Discussion can be built.</td>
</tr>
<tr>
<td>The Results section will present the findings of the research in both figures and in written text. Figures (graphs, tables and diagrams) present the complete findings in visual and numerical terms, while the accompanying text helps the reader to focus on the most important aspects of the results and to interpret them.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>This section is generally considered to be the most difficult part to write and it calls on the skills of the researcher to interpret the results obtained.</td>
</tr>
<tr>
<td>It presents an argument, or set of arguments, about the significance of the results, about any limitations or problems with research design or implementation and consequent proposals for future work.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>This section should include the references actually cited in the body of the paper.</td>
</tr>
</tbody>
</table>
The Lab Report

The lab reports you will write as an undergraduate student are modeled on research articles; however, there are some differences:

- The scope and complexity of the research article is greater than that of the lab report, particularly in the Introduction, Results and Discussion sections. For example, the Introduction of the research article will usually include a literature review that summarizes the previous research that has been done in the area being investigated. In a lab report, this literature review will probably not be so extensive;

- The audiences for the research article and the lab report are also different. The research article is written for research scientists who are specialists in their field, whereas the lab report is written for instructors or fellow students.

The format of the lab report is usually specified for each course. However, the general format given below may serve as a guideline (see Appendix 1 for a Lab Report Revision Checklist).

Title

The Title of the lab report should indicate exactly what you have studied. For example, a title such as “The effects of
light and temperature on the growth of the bacterium, *Escherichia coli*"* explains

1. the environmental factors manipulated (light and temperature),
2. the parameter measured (growth), and
3. the specific organism used (*E. coli*).

It is unnecessary to use words like “A study on the effect of…” or “A report on the…”

* Note that any specific organisms named should always be italicized.

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**Abstract**

The Abstract is a brief summary of your entire lab report (about 250 words). It belongs at the beginning of your report, before the Introduction. It is always written last, since it includes your main results and conclusions.

- Begin the Abstract with a brief, but specific, background statement to introduce your report.
- State your main purpose or objective and hypothesis.
- Describe the important points of your methodology (species/reagent/ingredient, the number of subjects or samples and technique or instruments used to make the measurements).
- Summarize the main results numerically and qualitatively (include standard errors and p values as required).
- Summarize the main points from the conclusion. Focus on the ones that directly relate to your hypothesis/question.
Use the **past tense** to describe the work and what was found; use the **present tense** for what is currently true.

**Introduction**

The Introduction provides the background information that the reader needs to understand your experiment (based on previous work and/or theory). The information that you provide for the reader will form the basis or foundation for your hypothesis. In the Introduction:

- Introduce the general area of science that your report deals with and explain why research in this area is important or relevant.
- Review the key concepts that are necessary for an understanding of the research that you are going to report on.
- Develop the scientific context. Review the current literature on the topic in order to provide a context for the hypothesis.
- State the hypothesis or purpose/aim of your research.

Use the **present tense** most of the time, but the **present perfect** and **past tenses** where logic demands. Resources such as your textbook, course notes, research articles can be used to determine the scientific concepts that are relevant to your research and to build the scientific context. Don’t forget to reference them.
Materials and Methods
(also called “Methods,” “Procedure,” or “Procedural”)

This section presents, in a logical order, the materials used and the procedure(s) by which the experiment was performed.

Describe what you did, using complete sentences and paragraphs, in the order that you did it (do not list). Include the materials (and quantities) as you use them (do not list them).

- Provide enough information and detail for someone else to reproduce your experiment.
  *Note: instructors will often ask you to write “please refer to the lab manual” and when you do this, reference it.

- Always document any changes that were made in procedures.

- Name all chemicals/reagents used (full name) and quantities with standard (metric) units.

- Use the past tense and the passive voice. For example: “Exogenous DNA was introduced...”

Results

This section is the “core” of the report. After reading the Abstract of a research article, professional scientists will then concentrate on this section. A well-written and well-organized Results section provides the framework for the discussion section.

The Results section should accurately report and describe all the data you have collected so that the conclusions you draw will be understandable to the reader. Do not interpret the data here.
Present your data in the form of percentages, averages, totals and so on. Put your raw data in an Appendix at the end of the report.

Use tables and graphs to present your data. Don’t forget to refer to the tables, graphs, diagrams in the text.

Summarize in sentences the highlights — trends, maximums, minimums, changes — of the tables and graphs.

Present sample calculations in a separate section titled “Calculations” or in an Appendix at the end of the report.

Use the **past tense**.

**Tables & Figures**

- Introduce each table or figure within the text and use the comment to point out the highlights.
  
  *e.g. The temperature increased on the third day (Figure 1).*

- Number each table and figure and provide self-explanatory titles so that the reader can understand their content without the comment.

  *e.g. Table 1. Percent of soybean plants exhibiting visible injury after exposure to acid precipitation.*

- Assign numbers to tables and figures in the order they are mentioned in the text.

- Number the tables and figures independently of each other. For example, the first table used in the lab report is Table 1, the second table is Table 2, and so on. The first figure used in the text is Figure 1, the second figure used
is Figure 2, and so on. This means you could have a Table 1 followed by a Figure 3; a Figure 4 followed by a Table 2.

- Refer to tables as tables and all other items (graphs, photographs, drawings, diagrams, maps, etc.) as figures.
- Put the title for tables at the top of the table; put the title for figures at the bottom of the figure.

**Discussion**

In this section you must analyze and interpret your results. One way to get started is to try to answer the question “What do these results mean?” in relation to the experiment’s purpose. The following specific questions may assist you:

- What (if any) are the major assumptions implied in your experiments?
- Do the results meet the experiment’s objectives?
- Do the results agree with expected results or with previous findings as reported in the literature? If not, how can you account for the discrepancy between your results and those expected? What may be wrong with published data that contradicts your results?
- What, if anything, may have gone wrong with your experiment, and why?
- Was there any source of error?
- Could the results have more than one explanation?
- Did the procedures you used help you to accomplish the purpose of the experiment?
• Does your experience with this experiment suggest a better method for the next time?
• Could another experiment be devised that may corroborate your result?

(Gilpin & Patchet-Golubev, 2000, p. 21)

Write down the answers to the above questions in point form. You then have to decide how you are going to organize this information. The following suggestions might assist you:

• One way to begin the Discussion section is by referring to your original hypothesis and accepting or rejecting it on the basis of what you have found.
• Then discuss the results, but first establish some kind of logical order for presenting them. This order may be similar to the one used in the Results section.
• Try and support your interpretations of the results with what is known in the literature.
• Write a conclusion at the end of your discussion of the results.
• Following the conclusion, you might want to discuss any further questions that the research raises.

References

Scientific lab reports are written for the sole purpose of sharing information. If readers want more information about what you’ve written, they need to be able to find the exact source. The reference page at the end of the report allows the reader to do this. References also give credit to the person who did the work and provide your work with authority.
Always reference your lab manual, lecture notes and any journal articles used. The textbook is usually referenced as well.

Never use direct quotations in your report; always paraphrase and give citations.

Consult your course instructors, lab manual, and course outline for proper referencing format. Many courses will specify the format of a particular journal.

The following sample biology lab report illustrates the language and structure of a typical lab report. References in this sample are formatted using APA style. This is a guide only; always check with your instructor for the specific course requirements.
EXAMPLE OF A LAB REPORT IN BIOLOGY:
The effects of pH on the rate of starch breakdown by the enzyme amylase.

Introduction

Amylase is present in both animals and plants where it catalyzes the breakdown of starch into dextrin and maltose. In animals this process occurs in the mouth and the small intestine, and in plants the products of starch breakdown are utilized during seed germination (School of Biological Sciences 1994).

Water hydrolyzes starch to produce smaller molecules (sugars), but the rate of reaction is very slow. Amylase increases the rate of hydrolysis by lowering the activation energy of the reaction. It forms a complex such that starch molecules fill active sites on the surface of the enzyme molecule. The presence of the enzyme increases the rate of starch breakdown, but the enzyme itself is not changed during the reaction (Purves et al., 1992).

Enzymes are very sensitive to conditions in their environment (e.g. temperature), since changes in conditions may alter their molecular structure. If this occurs, the active sites may not be available for the substrate molecules, and hence catalysis will not occur. pH is known to affect the ability of enzymes to catalyze reactions (Purves et al., 1992). This experiment was conducted to determine the optimum pH at which amylase catalyzes starch breakdown. The hypothesis to be tested was that the enzyme would show optimal activity at pH 7, since it was extracted from pig pancreas, and the normal pH of the pig gut is 7 (School of Biological Sciences, 1994).
Methods

A calibration curve was prepared to determine the relationship between starch concentration and absorbance readings on the spectrophotometer. This involved adding iodine, an indicator which turns blue-black in the presence of starch, to test tubes which each contained a different concentration of starch solution. The absorbance of each solution was read at 590 nm using the spectrophotometer.

A series of treatments was prepared using buffers at pH 5, 5.5, 6, 6.5, 7 and 8. Each test tube contained 2 ml 0.4 mg ml⁻¹ starch solution and 2 ml buffer solution. One ml amylase solution was added to each tube and the solutions left for 5 minutes. Four ml HCl was added to each tube to stop the reaction, after which 1 ml iodine was added.

Solutions were then examined using the spectrophotometer and their absorbance measured. The concentration of starch remaining in each tube was determined using the calibration curve, and rates of reaction, at each pH, calculated. A control tube was set up for each pH to determine if any reaction would occur without the enzyme. Four replicates were used for each treatment throughout the experiment, to give an indication of the variability within treatments.

Results

The calibration curve showed a positive linear correlation between starch concentration and absorbance, as shown in Figure 1.
When rates of reaction were plotted against pH, a bell-shaped curve was obtained as shown in Figure 2.

This indicated a peak amylase activity at pH 7 (mean rate = 9.95 mmol min$^{-1}$, range = 6.8 - 13 mmol min$^{-1}$). The rate of reaction declined markedly for pH values above or below 7 to lowest values at pH 5 (mean rate = 0.9 mmol min$^{-1}$).
Discussion

The results showed that amylase activity was dramatically affected by changes in pH. The enzyme worked most efficiently at pH 7 and was retarded at lower or higher pH values.

Variations in replicate results were high, probably due to changes in environmental conditions, variations in the equipment and its use (i.e. pipetting and spectrophotometer use), or differences in the prior experience of researchers.

The controls revealed that starch was not broken down in the time period of the experiment when the enzyme was absent. This would be expected given that the starch-water reaction is exceedingly slow if amylase is not present (Purves et al., 1992). The experimental results are in agreement with statements on enzyme action and behaviour (Purves et al., 1992; Lehninger, 1975) which indicate that the enzyme’s structure is altered at non-optimal pHs. They are also in agreement with the original hypothesis, in that amylase activity is most efficient at pH 7, which is that found in the pig’s gut.
References


School of Biological Sciences. (1994). *Biology 1 Laboratory Notes*, Volume 1. The University of Sydney.
Other Types of Student Writing

The Literature Review

The main purpose of a literature review is to critically analyse a published body of knowledge in a particular area. Depending on your assignment, the publications reviewed can include research articles, theoretical papers, case studies, books, other literature reviews and conference proceedings. These publications are summarised, grouped or classified, compared and evaluated.

A literature review can have two forms:

1. a stand-alone informative literature review paper assigned in a course, used as part of a student’s training in the research processes of their field; and
2. a chapter in a thesis or dissertation.

Depending on which form of the literature review you undertake, other purposes of the literature review can include:

- placing each work in the context of the subject under review, showing how it contributes to an understanding of this subject area;
- describing the relationship of each work to the others being reviewed;
- identifying inconsistencies, gaps and contradictions in the field;
ensuring researchers do not duplicate work that has already been done;
pointing the way forward to further research; and
placing one’s own work (in the case of theses or dissertations) in the context of existing literature.

The focus and perspective of your review and the thesis or position you argue will be determined by what kind of review you are writing. The stand-alone informative review synthesizes and interprets the major trends in the literature and attempts to critically evaluate this research. The chapter in a thesis or dissertation is written to develop an argument to justify a piece of research. This type of review is selective, only discussing literature that leads to the research. One way to understand the differences between these two types is to read published literature reviews (access Annual Reviews Online from the University of Guelph Library system) or the first chapters of theses and dissertations in your own subject area.

The stand-alone informative review is the type of literature review discussed in this section. An example follows which illustrates some of the structural features of such a review. References in this sample are formatted according to the journal’s own style, which is a variant of CBE style. This is a guide only; please check with your instructor as to the specific requirements of your course.

**Structure of the Review**

### Introduction

Introductions to literature reviews can vary in length from one paragraph to several paragraphs, depending on the nature of the topic and the guidelines of the assignment.
The average length is one to two paragraphs. Use the introduction to fulfill the following functions.

- Identify your general topic, the area of concern, issue, question being addressed, establishing the context for your review.
- Identify the overall trends in what has been published about the topic: are there conflicts in the theory, methodology, evidence used, conclusions?; are there gaps in the field — areas not addressed? questions not asked? problems not resolved?; are there new areas of research identified?
- Establish your purpose (point of view) for reviewing the literature.
- Describe the criteria you are going to use in analysing and comparing the literature.
- Outline how the review will be organized (the sequence).
- Explain why you will look at certain research studies but not others (scope).

The introduction in the following example is quite long. Your introduction does not have to be the same length; it should be only as long as is necessary to fulfill the requirements outlined above.
EXAMPLE OF AN INTRODUCTION
TO A LITERATURE REVIEW:
Approaches to the Study of Territory Size and Shape

INTRODUCTION

Territoriality can exert strong effects on the population dynamics of aggressive animals (Patterson 1980, Davies & Houston 1984, Lomnicki 1988, Newton 1992, Sutherland 1996). The nature of these effects depends in large part on how territory size is adjusted to ecological circumstances. When territory size is inflexible, local populations may be regulated at stable densities. By contrast, when territory area is readily altered owing to changes in food abundance or the density of competitor, population densities will also vary. Intraspecific variation in territory sizes may also lead to unequal division of resources among competitors, with consequences for differential rates of growth, mortality, and reproduction. The behavioural adjustment of territory size thus has important consequences for demography, population regulation and spatial ecology.

My goal is to provide an overview of theoretical studies of the causes of intraspecific variation in territory size and shape, paying particular attention to their potential for predicting population-level phenomena. I argue that the most common approach to the analysis of territory size, which is based on optimality models, is applicable only in limited circumstances. This is because optimality models are constructed to predict the unilateral decisions of focal residents, rather than the outcome of interactions of two or more competitors. In practice, the optimality approach has rarely allowed quantitative prediction of territory sizes or shapes in natural circumstances; even its qualitative
predictions can be difficult to test. Alternative approaches are described that explicitly consider the actions and decisions of multiple territory residents.

This review begins with a classification of behavioural models of territory size and shape. Three conceptual approaches are recognized, distinguished by what they view as the essential interaction or decision-making process controlling territory area. These are (a) focal resident models, (b) models of interactions among neighbours, and (c) models of interactions between established residents and potential settlers. Each of these approaches includes both mechanistic models, which demonstrate the effects of particular rules of behaviour, and optimality or game theoretical models, which derive the rules that maximize fitness. Mechanistic models are often built on the underlying assumption that behaviours are adaptive, but do not formally solve for optimal behaviour. Following this classification, I present a brief review of correlative and experimental studies on how territory size is affected by food availability and intruder pressure, the variables emphasized by the theory of optimal territory size. This is imperfectly understood and represents an issue for which development of a theory of territory interactions is needed.

Because it is not possible to discuss or even list all the papers with information on intraspecific variation in territory size in a review of this length, I instead illustrate key points with examples from diverse taxa. Interspecific differences in territory size, the relationship of territory sizes to mating and social systems, and related topics have been reviewed elsewhere (Schoener 1968, Emlen & Oring 1977, Waser & Wiley 1979, Davies 1980, Ydenberg et al. 1988, Newton 1992, Stamps 1994, Temeles 1994, Gordon 1997).
I adopt Wilson’s (1975) definition of territory as “an area occupied more or less exclusively by an animal or group of animals by means of repulsion through overt defense or advertisement.” This encompasses a broad range of territory types. At one extreme are territories with sharp limits, often revealed by the locations of distinctive behaviours shown at territory boundaries (e.g. Nursall 1977, Askenmo et al. 1994, Eason et al. 1999). At the other extreme are home ranges that overlap extensively, but that are nonetheless defended to some degree against conspecifics, especially within core areas (e.g. Getty 1981c, Stamps 1990).


An important aspect of the structure of an introduction is telling the reader how the review will be organized, thus forecasting the organization of the body of the review. Setting up this relationship between the introduction and the body of the paper is important in achieving clarity and flow in your writing.

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**Body**

The Body of the literature review should classify and organize your material according to the most useful or logical method.

- Classify or group the studies, reviews, articles according to criteria that you establish from having read the literature — purposes or objectives of the research; qualitative vs quantitative approaches; conclusions of authors; chronology; themes.
- Summarize the relevant aspects of the individual studies or articles.
- Use headings and subheadings in this section if appropriate.

The following example shows the headings and subheadings used by the writer to organize the body of the literature review. He has grouped the studies according to the different conceptual approaches taken in the research: different types of models, multivariate and experimental studies. The headings and subheadings follow the outline set out in the introduction.

**EXAMPLE OF THE ORGANIZATION OF THE BODY OF A LITERATURE REVIEW:**

**Approaches to the Study of Territory Size and Shape**

**FOCAL RESIDENT MODELS**
- Mechanistic Models
- Optimality Models: Components and Limitations
- Empirical Tests

**MODELS OF INTERACTIONS BETWEEN NEIGHBOURS**
- Mechanistic Models
  - Geometric Models of Territory Boundaries
  - Local Rules of Movement and Interaction
- Cost Benefit and Game Theoretical Models

**MODELS OF INTERACTIONS BETWEEN RESIDENTS AND POTENTIAL SETTLERS**

**FOOD AVAILABILITY AND INTRUDER PRESSURE AS DETERMINANTS OF TERRITORY SIZE**
- Multivariate Studies
- Experimental Studies on Food Availability
Conclusion

Your conclusion, like your introduction, must fulfill a specific set of requirements. Understanding what these requirements are will help you structure an effective conclusion.

- Keeping in mind the focus you established in the introduction, summarize the major contributions that the literature you have examined makes to the body of knowledge you have reviewed.

- Evaluate the literature you have reviewed, identifying major flaws or gaps in the research, inconsistencies in theories and findings, areas that should be further studied.

- Relate the central topic of the literature review to a larger area of study such as a discipline or a scientific endeavour.

Notice in the concluding section of our example review how the writer has made a connection between the introduction and conclusion by re-stating the goal of the review and then drawing his conclusion about it. He has also used his grouping of the different studies to organize the remainder of the conclusion, highlighting the strengths and weaknesses of the different approaches as well as the gaps in the field.
EXAMPLE OF A CONCLUSION
TO A LITERATURE REVIEW:
Approaches to the Study of Territory Size and Shape

CONCLUSIONS
The central goal of this review is to clarify conceptual differences among alternative approaches to territory modelling and to indicate the relationship of each approach to empirical studies. The main conclusion is that an expansion of theory beyond the now familiar optimality models will improve our ability to account for population-level effects of territory defense. I conclude by highlighting the strengths and limitations of the three major bodies of theory and by pointing to gaps in our current ability to evaluate these models.

Limitations of optimality models have been discussed because of the prominence of this approach. Because they focus on decisions by individuals and assume implicitly that territories are not contiguous, simple optimality models are not well suited to predicting the ecological consequences of territory defense in crowded populations. Furthermore this approach usually does not allow quantitative prediction of territory size in natural circumstances based on information that can be easily gathered. Nevertheless, some of the primary insights of the optimality approach have been confirmed, and the themes identified by this body of work must remain an integral part of territory studies. Optimality models encourage the investigator to examine time and energy budgets in an economic framework. This line of enquiry can reveal the criteria and decision rules used to select territory size (e.g. Hixon 1980). More generally, many empirical studies have shown that the abundance of food and costs of expelling intruders are important determinants
of territory area. However, surprisingly few experiments have been designed to distinguish between direct responses to increased food supply and indirect responses owing to attraction of competitors.

**Models of interactions among neighbours** are more useful, from the standpoint of population ecology, because they predict the outcome of interactions among multiple competitors in crowded populations. This approach encourages examination of mutual reactions among adjacent residents and how these mould the use of space. Several geometric models produce quantitative predictions of the size and shape of each resident’s territory. Although there is the potential for these models to become diverse and complex, it has been possible to account for much of the observed variation in territory size and shape by employing fairly simple assumptions (e.g. Adams 1998). However, geometric models have thus far been tested only by measuring correlations between observed and predicted territories, rather than by experimental factors hypothesized to affect boundary positions. Furthermore these models are mechanistic, rather than adaptationist, and they largely ignore responses to variable food supply.

An important goal for future studies is to link mechanistic models of boundary formation with the cost-benefit approach. This requires game theory, because the optimum choice by a particular individual depends on what other members of the population are doing. Instead of asking how a focal resident should change its behaviour when food supply increases, such a model would ask how the balance of aggression between two or more neighbours can be expected to shift when all individuals experience an increase in food abundance. This may allow an understanding of
which territorial systems are sensitive to changes in food availability and which are not.

**Models of contests between established residents and potential settlers** focus attention on the decisions of nonterritorial intruders as well as those of territory holders. Because the persistence of an intruder in attempting to acquire a territory should depend on its prospects for obtaining a territory elsewhere, this approach connects the behaviour of territory defense to large-scale patterns of distribution across patches. Of the three broad approaches reviewed here, models of resident-settler interactions produce the most complete description of the density-dependent effects of territory defense. They also predict the population responses to habitat loss and degradation (e.g. Sutherland 1996), linking territory behaviour to landscape and conservation ecology. Few field studies have been designed specifically to test this set of models, but there will be a considerable payoff for doing so.

A common problem with student literature reviews is that they are often just summaries of various pieces of research. For example, look at the following piece of writing:

Smith (2000) concludes that personal privacy in their living quarters is the most important factor in nursing home residents’ perception of their autonomy. He suggests that the physical environment in the more public spaces of the building did not have much impact on their perceptions. Neither the layout of the building, nor the activities available seem to make much difference.

Jones and Johnstone make the claim that the need to control one’s environment is a fundamental need of life (2001), and suggest that the approach of most institutions, which is to provide total care, may be as bad as no care at all. If people have no choices or think that they have none, they become depressed.

The writer is simply describing the various studies and what the researchers found. There is no comparison made between studies and no evaluation of the studies. The reader must be able to hear your voice. The following excerpt from the body of the literature review illustrates the writer’s critical stance.
EXAMPLE OF WRITER’S CRITICAL STANCE:
Multivariate Studies

Similar multivariate analyses have been conducted with other animals, with varying results. In some populations, there was no significant effect of food abundance on territory size once the intensity of competition was accounted for (Gauthier 1987, Dunk & Cooper 1994, Tripp & Collazo 1997). In others, food abundance was negatively correlated with territory size even after accounting for competitor density or chase rates (Dill et al. 1981, McFarland 1986, Temeles 1987, Truicas 1989). Occasionally, both prey density and competition by neighbours have significant independent effects (e.g. Temeles 1987).

Caution must be exercised in interpreting these and other correlative studies. Intrusion pressure can be difficult to quantify, and the aspects that are easiest to measure may not be those with the strongest effects on the resident’s behaviour. Few studies evaluate which measure is the best predictor of territory size (but see Temeles 1987). After territory boundaries have been established, the effect of neighbours may be missed because, in many species, neighbours rarely intrude yet have strong negative effects on territory size. In general, causation can be difficult to discern from correlations. Controlled experiments are the preferred way to determine the direction of causation, and the results of experiments do not always coincide entirely with correlative studies of the same species (e.g. McFarland 1986, Tricas 1989).

Getting started

~ **Step 1: Identify a working topic that interests you.**

- Look at your field of study; think about what interests you.
- Talk to your professor; read your lecture notes.
- Read recent issues of periodicals in your field.

~ **Step 2: Review the literature.**

- Search computer databases (at least 2) using keywords.
- Examine the reference sections of recent articles and read review articles: this can lead you to other valuable papers.

~ **Step 3: Narrow your topic and select papers accordingly.**

- Consider what interests you.
- Consider the time span of the research.

~ **Step 4: Read the articles thoroughly, and evaluate them.**

- What assumptions do most/some researchers seem to be making?
- What methodology is being used? — testing procedures, subjects, materials.
- What research findings and conclusions have been drawn?
- What experts in the field are cited?
- What conflicting theories, results, methodologies are presented?
- What theories have changed/remained the same?
Step 5: Find a focus — look for patterns.
- Note what themes or issues connect your sources together.
- Is there an aspect of the field that is missing?
- Is the material well presented?
- Is the material presented according to an appropriate theory?
- Is there a trend in the field? a debate?

Step 6: Use your focus to construct a thesis statement.

I argue that the most common approach to the analysis of territory size, which is based on optimality models, is applicable only in limited circumstances.

Your thesis statement will not necessarily argue for a position or opinion; it may argue for a particular perspective on the material.

The current trend in treatment for congestive heart failure combines surgery and medicine.

Step 7: Organize your paper based on your findings from steps 4 and 5.
- Develop headings and sub-headings.

Step 8: Write the conclusion.
- Consider the “big picture” based on what you have read.
Critical Review of a Journal Article

Writing a critical review of a journal article can help to improve your research skills. By assessing the work of others, you develop skills as a critical reader and become familiar with the type of evaluation criteria that will be applied to research in your field and thus your own research.

At the beginning of this book, the structure and content of a research/journal article was presented. This is the type of article you may be asked to critique. You are expected to read the article carefully, analyze it, and evaluate the quality and originality of the research, as well as its relevance and presentation. Its strengths and weaknesses are assessed, followed by its overall value. Do not be confused by the term critique. This does not mean that you only look at the negative aspects of what the researcher has done. You should address both the positive and negative aspects.

If your lecturer has given you specific advice on how to write a critical review, follow that advice. If not, the following steps may help you. These are based on the detailed description of how to analyze and evaluate a research article provided by Wood (2003) in her Lab Guide at http://www.micro.uoguelph.ca/jwood/mad/research_lab/guide.htm

Select a Topic

If you are not assigned a particular topic, and must select one yourself, think about using review articles in your field to assist you. In review articles, “experts explain … current knowledge of a particular topic, indicating which studies (research articles) have contributed to that knowledge, how they have contributed and what questions remain to be answered” (Wood, 2003, Lab 1, para. 3). Select a review article on a topic
that interests you, one in which you have some background. Choose one that is written clearly, in a way that is understandable to you.

**Select a Research Article**

Use the review article to select a research paper to critique. Selecting the research paper from a review article can be very useful in writing your critique. The review article will provide background information for your analysis, as well as establishing that the research paper you are critiquing is significant: if the paper was not so highly regarded, it would not have been selected to be reviewed.

When deciding which research article to critique, examine the methods section of the articles carefully. New or unusual methods are described in detail in the Materials & Methods section; others are listed in that section or in Table and Figure legends, and other methods are considered to be standard techniques in the discipline (Wood, 2003) and so will not be specifically mentioned. Make a list of the techniques used. It is important that you have a reasonable grasp of these techniques; the more complex they are, the more difficult it will be to evaluate them.

**Analyze the Text**

Do a careful reading or readings of the article(s) you are going to critique. As you read the article(s), use the following questions to help you understand how and why the research was carried out. Note the answers to these questions.
1. What type of article is it? (theoretical, experimental, a correlational study, research review; is it longitudinal, cross-sectional, time-lag design?)
   - Most relevant section: Abstract
2. What is the author’s central purpose?
   - Most relevant section: Introduction
3. What methods were used to accomplish this purpose (systematic recording of observations, analysis and evaluation of published research, assessment of theory)?
   - What were the techniques used?
   - How was each technique performed?
   - What kind of data can be obtained using each technique?
   - How are such data interpreted?
   - What kind of information is produced by using the technique?
   - Most relevant section: Methods
4. What objective evidence was obtained from the author’s efforts (observations, measurements, etc.)? What were the results of the study?
   - How was each technique used to obtain each result?
   - What statistical tests were used to evaluate the significance of the conclusions based on numeric or graphic data?
   - How did each result contribute to answering the question or testing the hypothesis raised in the introduction?
   - Most relevant section: Results
5. How were the results interpreted? How were they related to the original problem (author’s view of evidence rather than objective findings)?
Were the authors able to answer the question (test the hypothesis) raised?
Did the research provide new factual information, a new understanding of a phenomenon in the field, a new research technique?
How was the significance of the work described?
Did the reported observations/interpretations support or refute observations/interpretations made by other researchers?

- Most relevant section: Discussion

Adapted with permission of Professor Susan Lollis, Family Relations and Applied Nutrition, University of Guelph.

Establish the Research Context

Once you are reasonably familiar with the article, it is important to gain an understanding of the research context, both societal and intellectual. To establish the research context, questions such as the following should be addressed:

- Who conducted the research? What were/are their interests?
- When and where was the research conducted?
- Why did they do this research?
- Was this research pertinent only within the authors’ geographic locale, or did it have broader (even global) relevance?
- Were many other laboratories pursuing related research when the reported work was done? If so, why?
- For experimental research, what funding sources met the costs of the research?
- Was the selection of the research topic influenced by the source of research funding?
- On what prior observations was the research based? What was and was not known at the time?
- How important was the research question posed by the researcher?

This background information can then be used to help you understand the experiment(s) that you are critiquing. For example, you must have a clear understanding of the research question (or hypothesis) posed in the article; this background information will help to determine why that particular question was asked/why that particular hypothesis was being tested. Some of the answers to these questions can be found in the article itself, in the Introduction and Discussion sections — look at the articles that are cited in these sections. Read some of these articles. If you used a review article to help you select your journal article, it will be useful for establishing what other researchers are working on in that particular area and what aspects of the research they are focusing on. For a more detailed description of how you might go about answering these questions, see Labs 4 and 5 (Wood, 2003).

**Evaluate the Text**

After you have read the article and answered the questions in the previous section, you should have a good understanding of the research undertaken. You can now begin to evaluate the author's research. Making judgements about someone else's work is often the most difficult part of writing the review. Many students feel that, because they are new to a discipline, they do not have enough knowledge to make judgements of other people's work.
The following checklist may assist you:

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**Introduction**

- Read the statement of purpose at the end of the introduction. What was the objective of the study?
- Consider the title. Does it precisely state the subject of the paper?
- Read the statement of purpose in the abstract. Does it match the one in the introduction?
- Check the sequence of statements in the introduction. Does all information lead coherently to the purpose of the study?

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**Methods**

- Review all methods in relation to the objective of the study. Are the methods valid for studying the problem?
- Check the methods for essential information. Could the study be duplicated from the methods and information given?
- Check the methods for flaws. Is the sample selection adequate? Is the experimental design sound?
- Check the sequence of statements in the methods. Does all the information there belong there? Is the sequence of methods clear, pertinent?

---

**Results**

- Examine carefully the data as presented in the tables and diagrams. Does the title or legend
accurately describe the content? Are column headings and labels accurate? Are the data organized for ready comparison and interpretation? (A table should be self-explanatory, with a title that accurately and concisely describes content and column headings that accurately describe information in the cells.)

☐ Review the results as presented in the text while referring to the data in the tables and diagrams. Does the text complement, and not simply repeat, data? Are there discrepancies between the results in the text and those in the tables?

☐ Check all calculations and presentation of data.

☐ Review the results in light of the stated objective. Does the study reveal what the researcher intended?

~ Discussion

☐ Check the interpretation against the results. Does the discussion merely repeat the results? Does the interpretation arise logically from the data or is it too far-fetched? Have the faults/flaws/shortcomings of the research been addressed?

☐ Is the interpretation supported by other research cited in the study?

☐ Does the study consider key studies in the field?

☐ Are there other research possibilities/directions suggested?
Overview

☐ Consider the journal for which the article is intended. Are the study’s topic and format appropriate for the journal?

☐ Reread the abstract. Does it accurately summarize the article?

☐ Check the structure of the article (first headings and then paragraphing). Is all material organized under the appropriate headings? Are sections divided logically into subsections or paragraphs?

☐ Are stylistic concerns, logic, clarity and economy of expression addressed?

Adapted from Kuyper, 1991

Establish the Significance of the Research

Finally, it is important to establish whether the research has been successful — has it led to new questions being asked, new ways of using existing knowledge? Are other researchers citing this paper? The following questions should be answered:

- How did other researchers view the significance of the research reported by your authors?
- Did the research reported in your article result in the formulation of new questions or hypotheses (by the authors, by other researchers)?
- Have other researchers subsequently supported or refuted the observations/interpretations of these authors?
- Did the research make a significant contribution to human knowledge?
- Did the research produce any practical applications?
• What are the social, political, technological, medical implications of this research?
• How do you evaluate the significance of the research?

To answer these questions look at review articles to find out how the reviewers see this piece of research. Look at research articles to see how other people have used this work; what range of journals have cited this article? For more detailed information on how to answer these questions, see Lab. 8 (Wood, 2003).

Write your Critique

You have completed your analysis and evaluation of the journal article. How do you then put all this information together? Different disciplines have different formats. If your instructor has not provided a format for your critique, you might present it in the following way:

~ Introduction

In the introduction, cite the journal article in full and then provide the background to this piece of research, establishing its place within the field. Use the answers to the questions in Establish the Research Context to develop this section.

~ Body

Follow the structure of the journal article. Evaluate each section of the article — Introduction, Methods, Results, Discussion — highlighting the strengths and weaknesses of each section. Use the answers to the questions in Evaluate the Text to develop this section.
Conclusion

In this section, sum up the strength and weaknesses of the research as a whole. Establish its practical and theoretical significance. Use the answers to questions in “Establish the Significance of the Research” to develop this section.

The Abstract

You may be required to write an abstract in your early undergraduate years. An abstract is a condensed version of a scientific paper. It conveys the most significant information about the research, especially the results, and is placed at the beginning of the paper, after the Title and before the Introduction. Readers often decide, on the basis of the Abstract, whether or not to read the full article.

The Parts of the Abstract

The structure of the abstract follows the order of the experiment — Introduction, Materials and Methods, Results and Conclusions. Your abstract should answer the following questions.

1. What is the general topic being investigated and why is it important?
2. What is the specific question that is being addressed in this research?
3. How was the experiment carried out?
4. What were the main findings?
5. What were the main conclusions?
**EXAMPLE OF AN ABSTRACT:**

**Growth and nutrition of baldcypress families planted under varying salinity regimes in Louisiana, USA**

| Importance of general topic | Saltwater intrusion from the Gulf of Mexico is one important factor in the destruction of baldcypress (*Taxodium distichum* (L.) Rich.) swamps along the Louisiana Gulf Coast, USA. Recent restoration efforts have focused on identification of baldcypress genotypes with greater tolerance to saline conditions than previously reported. To date, salt tolerance investigations have not been conducted under saline field conditions. In 1996, therefore, three plantations were established with 10 half-sib genotype collections of baldcypress in mesohaline wetlands. Tree survival and growth were measured at the end of two growing seasons, and foliar ion concentrations of Na, Cl, K, and Ca and available soil nutrients were measured during the 1996 growing season. In general, soil nutrient concentrations exceeded averages found in other baldcypress stands in the southeastern United States. Seedlings differed among sites in all parameters measured, with height, diameter, foliar biomass, and survival decreasing as site salinity increased. Average seedling height at the end of two years, for example, was 196.4 cm on the lowest salinity site and 121.6 cm on the highest. Several half-sib families maintained greater height growth increments (ranging from 25.5 to 54.5 cm on the highest salinity site), as well as lower foliar ion concentrations of K, Cl, and Ca. Results indicate that genotypic screening of baldcypress may improve growth and vigor of seedlings planted within wetlands impacted by saltwater intrusion. |
| Specific research question |  |
| How experiment was carried out |  |
| Main findings |  |
| Main conclusions | Krauss et al., 2000, p. 153 |
Getting Started

~ **Step 1:** Read the article, paper, or report thoroughly with the goal of abstracting in mind.

~ **Step 2:** Look specifically at the main parts of the article, paper, or report: purpose, methods, results and conclusions. Underline key points.

~ **Step 3:** After you’ve finished reading the article, paper, or report, write a rough draft without looking back at what you’re abstracting.
  
  ▪ Do not copy key sentences from the article, paper, or report.
  
  ▪ Do not rely on the way material was phrased in the article, paper, or report; summarize the information in your own words.
  
  ▪ Check your draft against the original paper to make sure that it reflects the paper.

~ **Step 4:** If you are writing the abstract for a paper that is not your own, document the source in a reference section and in your title.
**Step 5:** Check that you are within your word limit (usually 250 words). Do NOT include:

- background details
- reference to the paper itself
- reference to the data
- quotations or sources
- opinions, personal comments
- new data, irrelevant data, figures, tables, examples, definitions.

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**The Poster Presentation**

A poster presentation is a condensed but highly visual way of delivering the fruits of your research to your readers. Poster presentations at scientific conferences (look for posters by your professors and teaching assistants in the hallways of your department) are excellent ways to convey or obtain information quickly and efficiently. At a conference, posters are hung in the same room — a sort of “art gallery” of recent scientific research — in which you can browse and examine as suits your interest or taste. Even though you may not prepare a poster presentation until your senior years, consider it a method of getting current research firsthand.

Like a lab report, the poster presentation is designed in sections: introduction, materials and methods, results, discussion, acknowledgements and references. Like the columns of a newspaper, the poster is designed so that these sections read from *top to bottom* first and then left to right to make reading easier and to allow for several readers to read simultaneously.
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Provide relevant background and context; explain clearly the purpose of your study. Use no more than two pages (20 point font).</td>
</tr>
<tr>
<td>Materials &amp; Methods</td>
<td>Because of the need for brevity, Materials &amp; Methods may be omitted. If you include it, highlight any unusual or special circumstances.</td>
</tr>
<tr>
<td>Results</td>
<td>As in the lab report or experimental paper, the Results section is the heart of the presentation. In poster presentations, text is rarely included; instead use graphs, figures, charts, diagrams and photographs along with explanatory notes.</td>
</tr>
<tr>
<td>Discussion</td>
<td>Present your discussion in point form (although sentences are acceptable) for ease of reading and emphasising the relevance of your findings.</td>
</tr>
<tr>
<td>References &amp; Acknowledgements</td>
<td>To accommodate space requirements, limit references and acknowledgements as much as possible.</td>
</tr>
</tbody>
</table>

The example of a poster presentation that follows shows how these sections might be organized.
Making a “Science” of Scientific Writing

Make Your Writing Familiar to Your Reader

Assuming that scientists must write so that they can be understood, it is important to realize that the meaning of what you write cannot be guaranteed:

We cannot succeed in making even a single sentence mean one and only one thing; we can only increase the odds that a large majority of readers will tend to interpret our [writing] according to our intentions (Gopen & Swan, 1990, p. 6).

Your goal in scientific writing is to come as close as possible to “guaranteed meaning,” and research has shown that readers understand better when information is structured and presented in a way that is familiar to them. If, as a writer, you understand this — and make your scientific writing “reader friendly” — you will have taken an important step in producing clear, concise, and understandable scientific writing.

Certain rhetorical strategies — the things writers do with language to make themselves understood by their readers — can give your work a better chance of being correctly understood and
interpreted. Approaching writing as methodically and scientifically as possible will help you considerably in “producing” good science.

**Keep Subjects Close to Their Verbs**

People generally anticipate that science writing will be “hard” to read. This is due both to the level of difficulty of the scientific concepts and the clarity (or lack of it) with which the scientific concepts are expressed. Regardless of the difficulty of the science, readers expect that the grammatical subject of a sentence (the person or thing “doing” something) will be followed quite closely by its verb (the action that the subject is “doing”). The following examples are difficult in both the nature of the scientific concepts and the way in which the sentences are constructed:

The participation of B-catenin in the Wnt signalling pathway and its activation of transcription through binding to TCF/LEF proteins, as well as B-catenin stability and degradation via glycogen synthase kinase 3 (GSK-3), along with another link to cell signalling that has been more recently unravelled (Fig. 3), have been well documented and reviewed.

(adapted from the *Journal of Cell Science*)

Wheat Head Blight or Scab, which has a multigenic background and is highly affected by ambient conditions found in warmer, drier locations (Bai and Shaner, 1994), and is a disease of significant economic importance in the temperate wheat growing regions of the world, is caused by Fusarium graminearum.

(adapted from the *Journal of Experimental Botany*)

The “B-catenin” passage is difficult to understand because cellular biology itself may be a difficult subject to understand and may require specialised background knowledge. The “Wheat
Blight” passage may also prove difficult in its consideration of cell wall structural proteins and “multigenic background.” However, both passages are “difficult” from another perspective: note that in both cases there are many, many words separating the subject (the “actor”) from its verb (the “action”).

As stated above, readers expect that a subject will be followed closely by its verb; yet in these passages, the grammatical subjects (“participation…activation” and “wheat head blight” shown underlined) are separated from their verbs (“have been well documented” and “is caused” respectively) by over 35 words. As a result, reader expectations have not been met, and understanding these sentences is difficult not only from the perspective of the concepts, terms, and jargon but also from the perspective of the sentence structure. Difficulty with both form and content make these passages hard to understand.

It may require more study to comprehend fully the scientific content, but re-structuring the sentences can make these passages considerably easier to read and understand:

It has been well documented and reviewed that B-catenin participates in the Wnt signalling pathway and activates transcription through binding to TCF/LEF proteins (Bienz, 1999; Brown and Moon, 1998; Gumbiner, 1998). Recently, B-catenin stability and degradation via glycogen synthase kinase 3 (GSK-3) have been unravelled along with another link to cell signalling (Fig. 3).

Wheat Head Blight or Scab is caused by Fusarium graminearum and has a multigenic background that is highly affected by ambient conditions found in warmer, drier locations (Bai and Shaner, 1994). It is a disease of significant economic importance in the temperate wheat growing regions of the world.
Even though these changes improve the chances that the message will be read clearly and efficiently, they represent only one way of improving the clarity of the above passages.

**Emphasize Important Information**

Just as we may experience stress in our lives, and engineers are concerned with stress forces in building bridges, your writing has points of stress too. The stress location in writing can be described as the information that you want to emphasise to your reader, and again readers generally expect that the most important information in a sentence will be located at the end of that sentence. Structuring your writing so that it follows this stress pattern helps your readers to read in a manner they expect, and it helps create a sense of “closure” or finality for the ideas in the sentence. Developing clear stress locations in your writing will help the rhythm of your prose and help guard against important information being lost or misunderstood by your reader. When potentially important information is placed in an unexpected location, readers (most often your instructors) will likely not understand your writing in the way that you want them to. Consider the following example:

Because there was no change in the retention time of PEX5-C upon addition of a peptide substrate, **we propose that PTS1 recognition occurs by a single PEX5-C polypeptide.**

(adapted from the journal *Nature of Structural Biology*)

This passage may be difficult to understand from a biochemical perspective; however, it is suitably constructed from a communication standpoint. The most important information that the authors want to express is found in the latter part of the
sentence, following previously established information that sets a context for understanding.

Even very long sentences can be clear if readers can identify stress locations. Compare the following examples:

This tentative structure assignment receives support from the relative thermodynamic stability of both geometrical azimine isomers (E)- and (Z)-13 which like (Z)-12 also appears to the sterically less congested and thermodynamically more stable isomer.

The relative complexity of azimine isomers aside, the sentence can be made clearer by identifying stress locations:

This tentative structure assignment receives support from the relative thermodynamic stability of both geometrical azimine isomers (E)- and (Z)-13; like (Z)-12, (Z)-13 also appears to the sterically less congested and thermodynamically more stable isomer.

(adapted from the *European Journal of Organic Chemistry*).

Adding a semicolon after (Z)-13 produces a “reading breath” that coincides with a stress location, the point where important information is held. The reader can then move on to tackling a new point that “builds” from previous information (a comparison with (Z)-12).

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*Set a Context for the Important Information*

If the stress position has given the reader the point to locate the emphasis of your sentence, then the *topic position* sets the stage for the appearance of the emphasized material: these two positions work in tandem. What your readers encounter in the *first* part of a sentence provides context and perspective for understanding fully what you are going to emphasize later in the
sentence. Furthermore, information in the topic position also refers back to previously discussed information that is now more familiar to the reader. Examine the following passage and note the way topic position information refers back to previous information and leads to stress position information, which in turn will set a context and perspective for new topic position material:

The **central nervous system of Aplysia** is remarkably well suited for studies of single cells. **Almost all its nerve-cell bodies** are large enough to permit the insertion of microelectrodes for intracellular recording. **Many of the cells** can be individually identified so that identical neurons can be examined in any number of individual animals under a variety of conditions. **Single cell bodies** can be dissected for biochemical studies. **Radioactive chemical substances or dyes** can be injected into the cell body and their movement throughout the neuron monitored morphologically and biochemically. **Unlike arthropods, the synaptic...connections** can often be monitored electrically, with minimal attenuation, by obtaining intracellular recordings in the cell body of the neuron. ...**The ability to trace connections from cell to cell** makes it possible to relate types of neuronal circuits and types of behaviour. ...**These technical advantages** made Aplysia attractive for the exploration of the rules governing the patterns of nervous connections and the relationship between different patterns of connections and behavior.

Kandel, 1976, p. 68

This passage is from the research of Professor Eric R. Kandel, recipient of the National Academy of Sciences Award for Scientific Reviewing. His research findings have received over 5000 citations and the above research from an important article discussing a small sea snail has itself been cited over 450 times, an indication of its value to the scientific community.

Notice that the topic position (the “central nervous system of Aplysia”) is established in the first part of the first
sentence with the emphasis then given to that system’s suitability for single cell study. The next sentence’s topic position reiterates the usefulness of the cell bodies before emphasizing that multiple procedures can be undertaken: individual neurons can be identified, “single cell bodies can be dissected,” radioactive chemicals can be injected, and electronic monitors can “trace connections from cell to cell.” All of these points contribute to a unified and easily understood passage of scientific writing designed to show the “technical advances” of *Aplysia*. Recognizing the topic and stress positions in your scientific writing can assist your reader in fully understanding your research.

**Focus Your Sentence Action**

Just as readers expect to find verbs following closely behind their subjects, so should those verbs clearly identify the action that is taking place in the sentence. Strong, assertive, and clear verbs are essential to communicating to readers what is occurring in a particular passage. Note the example below:

Shear stress- or blood pressure-dependent local biophysical properties are in our growth and remodeling model. Stress-dependent growth probability in inter-digitating vascular patterns is in the first and second simulations (Fig. 1, 2A). In contrast is an initially identical pattern of pressure-dependent remodeling in a dramatically different situation with venous part absence (Fig. 2B).

(adapted from the journal *Developmental Dynamics*)

By introducing stronger and more clearly positioned verbs to this passage and re-organizing some sentences, it can be much more easily read and understood.
In the first simulation (Fig. 1), and in a second simulation (Fig. 2A), shear stress-dependent growth probability is implemented that produces inter-digitating vascular patterns. In contrast, pressure-dependent remodeling (of an initially identical pattern) leads to a dramatically different situation with almost total absence of the venous part (Fig. 2B).
Grammar and Scientific Style

As noted elsewhere in this book, the scientific method — the process of developing and testing hypotheses and analysing the results of an experiment — depends on a certain amount of objectivity from the scientist. Your findings will have a greater chance of being duplicated by others according to your hypothesis and the way you carried out your experiment if you have maintained an objective stance. Even though complete objectivity is impossible, your readers expect that you have attempted to be as objective as reasonably possible in your science and your writing.

Use of First Person (I, We)

The use of first person pronouns and the passive voice (see below) in scientific writing are subjects of considerable misconception. It has been long assumed and practised that under no circumstances should a scientist use the first person “I” or “we”: this is simply not true and has probably resulted in a great many awkward and wordy expressions in scientific writing, precisely the problems scientific writing should strive to avoid.

However, many people who write in the sciences maintain that in order to establish as objective a stance as possible in your scientific writing, you should rarely use the first person pronouns “I” or “we.” As much as possible, your scientific writing should emphasise the conditions, methods, results, and discussion of the
experiment, not that you were the one who carried out the task. Using personal pronouns such as “I” or “we” too often might seem to indicate that your influence is the key to the experiment’s success and not the design and analysis of the experiment; however, in many professional scientific journals, there is some use of “we.”

In designing this...pilot study, we assumed that both safety and clarity of interpretation were of paramount importance. Therefore, we studied three carefully selected subjects with sickle cell disease (Table 1).

(adapted from the journal Blood)

The above example is acceptable according to the journal Blood; however, in much of your scientific writing in your academic programme, it is perhaps conventional and expected that references to the researcher as “I” or “we” will be removed:

In designing this proof-of-concept pilot study, it was assumed that both safety and clarity of interpretation were of paramount importance. Therefore, 3 carefully selected subjects with sickle cell disease were studied (Table 1).

This study compared the effect of desflurane and halothane on the action of phenylephrine (PE) in a vascular smooth muscle preparation Y.

(adapted from the Canadian Journal of Anesthesia)

While this issue is debatable, one of the principles of scientific writing discussed earlier in this handbook is reproducible results and universal applicability — permitting others to “re-create” the conditions and findings of your experiment. Therefore, restricting the use of “I” and “we” will allow you to place more emphasis on your methods and results and will help you highlight how the data you obtained leads to your specific conclusions.
Use of the Passive Voice

Closely allied to the limited use of first person pronouns — and part of the same misconception — is the use of the “passive voice” in scientific writing. Many readers of scientific writing expect the passive voice. When the subject performs the action, the verb is in the “active voice”; when the subject receives the action, the verb is in the “passive voice.”

<table>
<thead>
<tr>
<th>Active Voice</th>
<th>Passive Voice</th>
</tr>
</thead>
<tbody>
<tr>
<td>The disease drove the patient mad.</td>
<td>The patient was driven mad by the disease.</td>
</tr>
<tr>
<td>We identified 27 studies, comprising 40 distinct intervention arms over 30 902 person years of observation. (adapted from the British Medical Journal)</td>
<td>Twenty-seven studies, comprising 40 distinct intervention arms over 30 902 person years of observation, were identified by us. (adapted from the British Medical Journal)</td>
</tr>
<tr>
<td>Using meta-regression, we further explored the relation between mean follow up and cardiovascular events. (adapted from the British Medical Journal)</td>
<td>The relation between mean follow up and cardiovascular events was further explored through meta-regression. (adapted from the British Medical Journal)</td>
</tr>
</tbody>
</table>

There are, however, two sides to every issue. While it is true that using the passive voice in scientific writing will emphasise the methods and results of your experiment, many scholars of scientific writing have stated that needlessly passive verbs and phrases will deaden your writing and result in awkward and unclear expression — again, problems to be avoided whenever possible in scientific writing. The strategy of
eliminating the passive voice in the following example strengthens the writing, according to Michael Alley:

The feedthrough **was composed of** a sapphire optical fibre, which **was pressed** against the pyrotechnic that **was used** to confine the charge. [passive]

The feedthrough **contained** a sapphire optical fibre, which **pressed** against the pyrotechnic that **confined** the charge. [active]

However, this is further complicated by recognising that scientific writing must be clear; as Alley points out, sometimes using the passive voice may be the clearest way of expressing your meaning:

On the second day of our wildebeest study, one of the calves wandered just a few yards from the herd and **was attacked** by wild dogs. (Alley, 1987, p. 60)

These are guidelines for using the first person and passive voice and not rules, and it is always best to follow your instructor's requirements, examples, and suggestions; however, provided that your writing emphasises and directs your reader to the science of your written document, it may be acceptable to use both first person pronouns and the passive voice constructions.

**Avoid “Creative” Language and “Value Judgements”**

Your writing style is very much a reflection of your personality, and, as stated above, elements of personality generally take a backseat to your science. Strong, active, clear and concise scientific writing rarely includes figurative language; that is, the type of “picturesque” language you might find used by your favourite poet or novelist. Any language that obscures or
draws attention away from your scientific findings or analysis should be removed:

The compound turned a bright sky-blue when the solution was added.

There is no therapy, and euthanasia is recommended — which is the way it should be — when the disease progresses and the horse is debilitated.

Similarly, to indicate to your reader that some effect or outcome is “interesting,” “helpful” or “unusual” is both subjective and lacking in scientific “distance.” More importantly, these terms are weak, imprecise and offer little scientific information to your work and writing. Furthermore, many scientific writers will not use the term “successful” (as in “The experiment was successful”) preferring instead to comment on success as it pertains to the research question: “The experiment as designed produced…”

Recognise Shifts in Verb Tense

Verb tense in scientific writing follows convention, and is fairly complex in its application. Robert Day (1994) notes that proper use of verb tense “derives from scientific ethics” (p. 164). Simply put, if it has been published in a recognised peer-reviewed journal, then it constitutes “established knowledge.” In citing anything from such a journal article or book you are expected to use the present tense.

Risk of protein-energy malnutrition (PEM) increases with loss of appetite, decrease in % usual weight, and increased % weight change in the previous year.14–18

(adapted from the Canadian Journal of Public Health)
The use of the present tense and the superscripted citations “14-18,” indicating that the author has taken this information from the five references, asserts that this is established and “verifiable” knowledge. In contrast, experimental work that you carry out is referred to in the past tense — most readers will not view your work as established knowledge, primarily because it has not, at the time of its research and writing, been verified, reviewed by professional scientists, and published.

In the course of a typical scientific paper, you will move from present to past tense several times. The following chart shows the sections of a scientific lab report and the tenses used (examples adapted from the Journal of Forensic Sciences).

<table>
<thead>
<tr>
<th>Section</th>
<th>Tense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>past tense (refers to your own work)</td>
</tr>
<tr>
<td></td>
<td>Forty-five of 56 lighter fluid constituents and 126 of 133 turpentine [sic] constituents were identified in the debris from a fire staged for each respective accelerant.</td>
</tr>
<tr>
<td>Introduction</td>
<td>generally present tense</td>
</tr>
<tr>
<td></td>
<td>But the supply of clean water, though also finite, is at least infinitely renewable.</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>past tense (again, your own procedures)</td>
</tr>
<tr>
<td></td>
<td>Fire debris samples were collected from a controlled burn of a couch conducted on-site, accelerated by the addition of 1 L of ignitable fluid</td>
</tr>
<tr>
<td>Results</td>
<td>past tense</td>
</tr>
<tr>
<td></td>
<td>Due to the compositional diversity in both the ignitable fluid... the weathering characteristics of the ignitable fluids differed slightly, but seemed to fall into one of the two weathering patterns.</td>
</tr>
<tr>
<td>Discussion</td>
<td>generally present tense</td>
</tr>
<tr>
<td></td>
<td>Nationally, about one in five reported fires is of suspicious origin.</td>
</tr>
</tbody>
</table>
To summarize: “In short, you should normally use the present tense when you refer to previously published work, and you should use the past tense when referring to your present results” (Day, 1994, 165).

It should be noted, however, that when “attributing” and referring directly to information in your research, it is correct to say ‘Smith (9) showed that streptomycin inhibits S. nocolor’… and ‘Table 4 shows that streptomycin inhibited S. everycolor at all pH levels” (Day, 1994, p. 165). Furthermore, “the results of calculations and statistical analyses should be in the present tense” even if they refer to objects in the past tense: “These values are significantly greater than those of the females of the same age, indicating that males grew more rapidly” (Day, 1994, 166).

Make Your Writing Concise, Precise and Simple

While you should avoid words and phrases that are subjective and vague in all your writing, this strategy is especially important in scientific writing. It will likely mean nothing to your reader that “There was not much change in the subject’s temperature.” Similarly, to say that the “The subject’s reaction to the administered solution was almost immediate” is to offer very little useful scientific information. These phrases are weak vehicles for conveying scientific meaning.

Alternatively, writing that an outcome in your experiment is definite and absolute must also be carefully considered. To proclaim, for instance, that the immersion of a particular substance will “always produce a certain result,” or that a certain experiment “proves something” is not usually seen as appropriate scientific writing. Rather than stating that you have “proved” your
hypothesis, your writing should convey whether or not the results of your experiment *support your hypothesis*.

Say it once and say it briefly: making your writing concise and precise depends on removing redundant words and phrases leaving only the essential scientific elements of what you want to communicate. Compare these originals with their revisions:

<table>
<thead>
<tr>
<th>Original</th>
<th>Revised</th>
</tr>
</thead>
<tbody>
<tr>
<td>In light of the fact that costs for solar energy options have been cut in half … (Alley, 1987, p. 69)</td>
<td>Because costs for solar energy options have been cut in half …</td>
</tr>
<tr>
<td>The aluminium metal casing was broken during incubation.</td>
<td>The aluminium casing was broken during incubation.</td>
</tr>
<tr>
<td>Thus it behooves us to be cognizant of this complex situation … . (adapted from the journal <em>Food and Chemical Toxicology</em>)</td>
<td>Thus we must recognize this complex situation…</td>
</tr>
</tbody>
</table>


Common Writing Faults

Examine your writing at several levels, from larger units to smaller: section structure, paragraph structure, sentence structure, and word choice. Here are a few common writing faults:

The Sentence Fragment

Sentences must have a subject, a verb, and a “complete meaning.” The underlined phrase below is a fragment (a dependent clause) — it needs “support” for meaning from the complete sentence it follows and, therefore, cannot be separated by a period:

FRAGMENT
Furthermore, EDTA or potassium oxalate anticoagulants and...staining techniques may mask some red blood changes. Such as basophilic stippling.

COMPLETE SENTENCE
Furthermore, EDTA or potassium oxalate anticoagulants and...staining techniques may mask some red blood changes, such as basophilic stippling. (adapted from the Canadian Veterinary Journal)
Conjunctions

Conjunctions join and relate words, phrases and clauses.

Co-ordinating Conjunctions connect words and phrases of equal grammatical weight (e.g. complete sentences). “FANBOYS” (For, And, Not, But, Or, Yet, So) is a way to remember co-ordinating conjunctions.

THIS:
The arc of the foot flight was very low, and the forward phase of the stride was minimal. (adapted from the Canadian Veterinary Journal)

NOT THIS:
The arc of the foot flight was very low, the forward phase of the stride was minimal.

Subordinating Conjunctions connect dependent clauses to main clauses. Examples of subordinating conjunctions are: although, after, as if, because, since, when.

THIS:
Although there are no reports of Tyzzer’s disease being treated successfully, early and aggressive therapy for septic shock may prove helpful. (adapted from the Canadian Veterinary Journal)

NOT THIS:
Early and aggressive therapy for septic shock may prove helpful. Although there are no reports of Tyzzer’s disease being treated successfully.
The “However-Semicolon” Disease and Conjunctive Adverbs

A conjunctive adverb is used to relate and connect main clauses: examples are consequently, furthermore, hence, indeed, consequently, therefore, however, nevertheless, still, then, thus.

Semicolons can be used in very few instances in English (unlike commas which have many uses). The semicolon joins complete sentences showing a close relationship (it is a softer separation than a period).

THIS:
This lesion may have caused the right fore- and hind-limb lameness; however, one would expect with a cervical lesion that the hind limbs would be more severely affected … (adapted from the Canadian Veterinary Journal).

NOT THIS:
This lesion may have caused the right fore- and hind-limb lameness, however, one would expect with a cervical lesion that the hind limbs would be more severely affected …

Joining two sentences with a comma is called a comma splice and is incorrect, even with the use of however. In most cases, conjunctive adverbs (however, therefore, moreover, accordingly, furthermore), as well as transitional phrases (as a result, as a consequence of) that join two sentences must appear as in this model:

[Sentence one]; however, [Sentence two].

[Sentence one]; as a result, [Sentence two].
**Keeping Verbs as Verbs**

Verbs “converted” into nouns are called “nominals,” and they slow the pace of your writing to a walk rather than a brisk trot. Making a verb into a “thing” will add both unnecessary length and a plodding rhythm to your writing. Nominals can often be identified by their suffixes (located at the end): -ment, -tion, and -ance (and sometimes -ity, -ize, and -ness). Use the following chart to familiarize yourself with sentence structures that avoid the use of nominals.

<table>
<thead>
<tr>
<th>“…the establishment of…”</th>
<th>THIS:</th>
<th>NOT THIS:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To establish the origin of the disease...</td>
<td>In order to learn about the establishment of the disease...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>“…the completion of…”</th>
<th>THIS:</th>
<th>NOT THIS:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The dog had not vomited for 15 h, but diarrhea began shortly after surgery and the patient vocalized constantly. (adapted from the <em>Canadian Veterinary Journal</em>)</td>
<td>The dog had not vomited for 15 h, but diarrhea began shortly after the completion of surgery and the patient continued to vocalize constantly.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>“…the commencement of…”</th>
<th>THIS:</th>
<th>NOT THIS:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hepatic encephalopathy ensues and death occurs soon after seizures begin. (adapted from the <em>Canadian Veterinary Journal</em>)</td>
<td>Hepatic encephalopathy ensues and death occurs soon after the commencement of seizure activity.</td>
</tr>
</tbody>
</table>
The Revision Process

Writing is never completed ... it is only due.

In preparing your paper, allow yourself ample time for the revision process; most writers will agree that the revision process is a pleasant one (especially compared to the struggles involved in generating the first draft). Interpret the word revision as re-VISION: “See” your paper again; look at it objectively, sceptically, even as if it is not your own work; ask questions about it. Cut those lovingly crafted sentences where necessary — this can be a painful (but necessary) process:

Strive for economy; shorter communications are usually better communications.

The reliability of a battery of diagnostic tests used to confirm a diagnosis of lead toxicosis is the subject of controversy. [21 words]

Reliability of diagnostic laboratory tests in confirming a diagnosis of lead toxicosis is controversial. [14 words]
Keep only what is essential: repeat nothing.

- very unique ⇒ unique
- combine together ⇒ combine
- important essentials ⇒ essentials
- mix together ⇒ mix

Employ forceful, active verbs balanced with passives.

Use transitional words and phrases sparingly.

Transitional words and phrases are often weak and imprecise “lead-ins.” Therefore, avoid phrases such as the following:

- “Initially…”
- “In any event…”
- “It can be seen…”
- “It is important to note…”

Edit imprecise and redundant phrases.

As part of the writing process, you may hurriedly include much information and many phrases and constructions that you should edit and refine during later revisions. The following are examples of such imprecise and redundant phrases:

- “it can be seen that…”
- “it may be that…”
- “in the final analysis…”
- “in respect to…”
- “in the case of…”
*Inject some sentence length variety into your document.*

Try to include some variety, but strive for “medium” length (roughly 20 words). It is often the *complexity* of sentences and not necessarily their *length* that confuses readers.

**Avoid using quotations.**

**Use relatively few “signposts” such as the following:**

“I will analyze...”;

“This factor was discussed above...”
References

These references are formatting using APA style.


Appendix 1

Lab Report Revision Checklist

Title
☐ is it an adequate description of the work done?
☐ does it provide key words for indexing?
☐ does it avoid abbreviations and jargon?
☐ does it avoid ‘empty’ words such as “studies on” and “an investigation of”?

Abstract
☐ does it state the main objectives — what you investigated and why?
☐ does it describe the methods?
☐ does it summarize the most important results?
☐ does it state the major conclusions and their significance?
☐ is the word range within the required limit?
Introduction

- does the introduction move from general to specific?
- has the subject of the report been indicated in general terms (relevance, importance)?
- has your specific area of interest been identified and what other researchers know about it been presented?
- has the relationship between your research and previous research been shown?
- is there a clear statement of purpose and/or hypothesis?
- are any sources properly referenced?

Materials & Methods

- have you given an accurate description of the materials used in the experiment?
- have you given an accurate description of the steps followed in carrying out the experiment?
- are the steps presented in chronological order?
- is there sufficient information for the steps to be duplicated by someone else?
- is the past passive the main tense used?
Results

☐ are the appropriate figures (tables, graphs, diagrams) presented?
☐ are there statements that locate the ‘figures’ where the results can be found?
☐ are there statements that present the most important findings?
☐ are there statements that comment on the results?
☐ are multiple results ordered logically (most to least important; simple to complex; organ by organ; chemical class by chemical class)?

Discussion

☐ does it move from specific to general e.g. your findings ⇒ literature, theory, practice?
☐ are the most important findings summarized?
☐ have you related your findings to your original hypothesis or research aim? did the study achieve its goal — resolve the problem, answer the question, support the hypothesis?
☐ have you related your findings to the literature (agreement, contradiction, exceptions)?
☐ have you indicated the limitations of your research?
☐ have you discussed the implications of your findings for future research?
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Referencing in the Sciences

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