Good communication is essential to scientific research. Investigators communicate the results of their work in the form of scientific papers that are typically published in journals (i.e., periodicals) that are specific to a particular field of study. Such papers are commonly referred to as primary literature.

Although each journal has its own specific guidelines for paper format, the basic foundation of all scientific papers is similar. In general, a paper must describe:

- A question or problem to be investigated.
- A protocol or experiment used to investigate the problem.
- Data and observations gathered from the experiment.
- An answer to the question (i.e., a conclusion) based on the observations.

These critical areas are usually addressed in different sections of the paper. In addition to an appropriate title, a typical paper will include the following sections, each clearly identified with its own section heading: Abstract; Introduction; Materials and Methods; Results; Discussion; Acknowledgements; and Literature Cited.

**Beware of Plagiarism!**

Plagiarism is the use of someone else’s work (ideas, words, images, etc.) and claiming them (directly or implicitly) as your own. Plagiarism can range from direct copying of text from outside sources to sharing of graphs among lab partners. Paraphrasing, rearranging, or reformatting another’s work still constitutes plagiarism. If you use someone else’s work, you must credit the source (see Appendix 2).

At Colby, we take this offense very seriously. Ignorance of the rules is not a defense. Anyone found plagiarizing is subject to a failing grade and disciplinary action from the Dean of Students.

**TITLE**

Every scientific paper must have a self-explanatory title. In general, the title should convey the variable or environmental factor that was manipulated, the measurement that was taken and the specific organism or biological system that was studied.

For example, “The effect of light intensity on the growth of Escherichia coli” would be an appropriate title. In contrast, titles such as “The effect of light on bacteria” or “A biology lab report” would fail to convey all the necessary information.

**ABSTRACT**

The abstract section in a scientific paper is a concise, self-explanatory digest of the content of the paper. The abstract should present, in about 250 words, the purpose of the paper, basic protocol, summarized results, and the major conclusions. Detailed background information, analysis, and descriptions are excluded, as are tables, figures and (typically) citations.

**WRITER’S TIP:** Write your abstract last. A useful approach is to summarize the most important points from each section of the paper in a few concise sentences and then assemble those sentences to construct a brief description of your study.
INTRODUCTION

The Introduction has three key components: relevant background information, a specific statement of purpose, and your experimental hypothesis.

The background should give readers enough information to appreciate your specific objectives within a larger theoretical framework. This will often include a summary of previous research that has been done on this problem, and will indicate how the present experiment will help to clarify or expand the knowledge in this general area. All background information gathered from other sources must be appropriately cited. (The proper formatting of citations in the text of the paper is detailed in Appendix A.)

The statement of purpose should clearly indicate the question or problem being investigated. As with the title, this should be sufficiently detailed; be sure to indicate the specific variable(s) being manipulated, the parameter(s) being measured, and the specific organism(s) or biological system(s) studied.

The introduction would also be the appropriate place to present your experimental hypothesis. A hypothesis represents an expected outcome, often based on prior research. A hypothesis is more than just a guess—it must be scientifically valid, and the reasoning behind it must be clear from the background information you have provided.

WRITER'S TIP: An introduction usually progresses from a general theoretical framework to a specific question. However, do not make the Introduction too broad—keep in mind that your target audience should have a level of knowledge similar to yours. Present only the most relevant ideas and get quickly to the point of the paper. You may find it that writing the Introduction after you have drafted your Methods and Results helps to provide a bit of focus.

MATERIALS AND METHODS

The Materials and Methods provides a description of the protocol employed in the investigation, including the experimental design, apparatus used, methods of gathering data, and type of control. In brief, sufficient information should be provided so that a reader could duplicate your study if they choose to do so.

Because your target audience is a group of researchers with similar knowledge and skills as you, it is NOT necessary to detail "standard procedures" such as using a microscope or loading an agarose gel. Also, complex procedures that are documented elsewhere are sometimes described simply by citing the original source. (e.g., "Respirometers were assembled as described in Colby (2007).")

WRITER'S TIP: The Materials and Methods is a past tense narrative of your experimental procedure—do not write it as though it were a set of directions in a laboratory handout, do not include lists of equipment or supplies. The following examples illustrate the wrong and right way to approach this section.

WRONG: "First pour agar into six petri plates. Then inoculate the plates with the bacteria. Then put the plates into the incubator. Wait ten hours."

RIGHT: "Six petri plates were prepared with agar and inoculated with the bacteria. The plates were incubated for ten hours."

RESULTS

The Results provide an objective presentation of the information gathered in the investigation. Here, data collected in the experiment are summarized and organized into a meaningful form that can be used to address the experimental question posed in the Introduction. This section includes any figures, tables or graphical representations of data as well as narrative text stating the statistical findings, general trends and serving as support for any figures and tables. Although it may seem like a simple task, crafting an
effective Results section can be quite challenging—the following guidelines will help you focus your efforts:

- **DO NOT** present raw data! Use *descriptive statistics* (such as mean and standard error) to describe the central tendency and variability of groups. (See the separate handout *Working with Statistics* for a detailed discussion of descriptive statistics.)

- When presenting three or more numerical results, it is usually best to display the information in a properly formatted **FIGURE** or **TABLE**. (Detailed instructions for formatting figures and tables can be found in Appendix A.)

- **DO NOT** repeat the same data in multiple formats. For example, if you display your means in a figure, you should not also include those values in a table or list them in the text.

- Figures and tables must **NEVER** be left to stand alone. The Results section always includes **NARRATIVE TEXT** that references each figure or table by number and summarizes the important information presented in each.

- The text of the Results is also the place to present the results of any **STATISTICAL TESTS** that you may have employed. (See the separate handout *Working with Statistics* for a detailed discussion of the calculation and presentation of comparative statistics.)

- Lastly, keep in mind that the Results is **NOT** the place to interpret or draw biological conclusions from your data. These will be developed in the next section of the paper.

**WRITER'S TIP:** Your job is to convey information as clearly and concisely as possible. Before you begin to draft your Results, consider the following questions:

*What is the important message that I want my reader to see?*

Answering this question requires that you have a firm grasp of the problem you are investigating, since your results will ultimately be used to support your conclusion (i.e., the answer to your experimental question).

*How do I best convey that information?*

Answering this second question largely depends on the type of data you are presenting—a figure (i.e., graph, chart, or picture) is often a great choice, but not all data is appropriate for this type of presentation. Sometimes a table or even just text is a better choice.

**DISCUSSION**

The Discussion provides **an interpretation of the information gathered in the investigation.** This involves two major components. First, it's where you offer your **conclusion.** The conclusion is an answer to your experimental question, **based on your results.** This is an important point and it bears repeating—your conclusion must be supported by the empirical evidence gathered during your experiment and presented in your Results.

Second, the Discussion should place your findings into the **broader biological context.** This should include valid but speculative biological explanations of why certain results were observed. Outside sources (properly cited) may be employed to support your explanation. In addition, you should consider why what you have learned is important. What are the implications for further research? What questions remain unanswered?

Note that it is **not** a requirement that you reach a particular conclusion (i.e., "get the right answer") or that your conclusion "fits" your hypothesis. Often this will not be the case! When this happens, you should speculate on its meaning. Do you need to revise your hypothesis, your methodology, or both? Experiments do not always need to show major differences or trends to be important. "Negative" results also need to be explained and may represent something important—perhaps a new or changed focus for
your research. Try to end your Discussion with a positive concluding remark and avoid the common pitfalls of explaining unexpected results as “human error” or creating a hypothetical list of things that may have gone wrong.

WRITER’S TIP: A useful strategy in discussing your experiment is to relate your specific results back to the broad theoretical context presented in the Introduction. Since your Introduction progressed from general background to a specific question, structuring the discussion to progress from your specific conclusions back to a broader general context will help to tie your ideas and arguments together.

ACKNOWLEDGEMENTS

In the Acknowledgements you give credit to people who have helped you with the research or with writing the paper. (In introductory biology this will typically include your lab partners or the other students in your lab section.) If your work has been supported by a grant, you would also give credit for that in this section.

LITERATURE CITED

This section a full citation for all published information referred to anywhere in the text of the paper. Such citations allow interested readers and other researchers to access the original literature relevant to your study. (The proper formatting of citations both in the text of the paper and in the Literature Cited section is detailed in Appendix B.)
APPENDIX A: THE CONSTRUCTION AND USE OF TABLES AND FIGURES

Summarized data presented in columns and rows are referred to as tables. All other items (graphs, pictures, drawings, maps, etc.) are referred to as figures. Do not refer to figures as "graphs" or "charts."

Tables often are used to present many numerical values. For example:

Table 1. Mean daily temperatures (± 1 SE) measured during three seasons of 1994 for the atmosphere and for portions of the Colby-Marston bog mat exposed to differing amounts of sunlight. (n=92)

<table>
<thead>
<tr>
<th>Location</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>19.3 ± 1.9</td>
<td>23.9 ± 2.6</td>
<td>20.5 ± 1.7</td>
</tr>
<tr>
<td>Open mat</td>
<td>16.7 ± 1.8</td>
<td>19.6 ± 2.3</td>
<td>18.6 ± 2.3</td>
</tr>
<tr>
<td>Shaded mat</td>
<td>11.1 ± 1.6</td>
<td>12.4 ± 1.2</td>
<td>13.8 ± 1.2</td>
</tr>
</tbody>
</table>

General Rules for Table Construction

1. Number tables consecutively and separately from figures.

2. The table must have a title with sufficient descriptive information so that the reader can interpret the table without having to refer to the text. Place the title legend left-aligned above the table.

3. Avoid the use of vertical lines whenever possible. Columns can be denoted by the use of horizontal lines below column headings and by spacing between the columns.

4. Try not to leave a large amount of blank spaces in tables. Resize the width of columns and rows to accommodate the data within it.

5. When giving measurements, use the correct number of decimal places/significant figures and be consistent. Be sure to provide units for all measurements.

Figures are used when it is desirable to present the results in a visual form in order to facilitate making comparisons among treatments. The type of figure chosen depends on the type of data being presented. When the independent variables share a quantitative relationship, a scatter plot is usually the best choice to emphasize trends. For example:

Figure 1. Plasmolysis of *Allium* bulb outer epidermal cells in external sucrose solutions at various concentrations. Number of cells observed = 230 / treatment.
However, when treatments do not have a quantitative relationship, a scatter plot is not appropriate. In such cases, a bar graph is a better choice:

![Bar graph showing mean gas production by yeast respiration in media supplemented with various sugars.](image)

**Figure 1.** Mean gas production by yeast respiration in media supplemented with various sugars.

### General Rules for Figure Construction

1. Number figures consecutively and separately from tables.

2. The figure must have a title with sufficient descriptive information so that the reader can interpret the figure without having to refer to the text. Place the title legend left-aligned under the figure.

3. Label each axis with units of measurement. Instead of simply labeling the axis as "Time", it should read "Time (seconds)".

4. The independent/predictor variable is generally placed on the X-axis (horizontal), the dependent/response variable on the Y-axis.

5. Distinguish between different sets of observations by using different symbols or lines and including a legend. If only one dependent variable is graphed, a legend is unnecessary.

6. As much as possible, the figure should be approximately square and not disproportionately exaggerated in one direction or the other.

7. When designing two (or more) figures that will be compared, be sure to use the same range of values on the axes to make comparisons easier.
APPENDIX B: USE OF CITATIONS IN SCIENTIFIC WRITING

In writing for peer-reviewed journal articles, there is no standard citing procedure as there is in other disciplines (APA, MLA etc). Instead the author follows the guideline of the specific journal that he/she wishes to submit the paper. Most scientific journals follow a similar format, but each may have some minor differences in arrangement and style (italics, capitalization). For your papers, use the following guidelines.

In text-citations:

The name(s) of the author(s) and year of publication are included parenthetically in the body of the text at the point at which the cited information is used. Study the following examples for format, and note that sentence structure determines the placement of the parentheses.

1. **One author:**
   b. Stander's (1992) study of lions...

2. **Two authors:**
   a. Previous studies have shown that inhibitory agents exist in walnut trees (Jones and Green, 1963).
   b. Jones and Green (1963) show...

3. **Three or more authors:**
   a. In response to pressure by predators, Elk will select habitat in opposition to their dietary needs (Creel et al., 2005).
   b. Creel et al. (2005) reported that...

If there are multiple citations at the end of a sentence, they should be ordered first chronologically by year and if the years are the same, then alphabetically.

Entries in Literature Cited:

Entries in the Literature Cited section are listed alphabetically by author(s) and chronologically for papers by the same author(s). The following citations illustrate the details of punctuation and order of information for a journal article, book, Internet source, and a laboratory handout.


Generally, most references will be to the primary literature (i.e., journal articles) and, to a lesser extent, books. Popular literature and the Internet should be used sparingly and with caution. Other sources such as book chapters and pamphlets typically have their own specific citation formats. If necessary, be sure to find out what these formats are and use them appropriately.

Also, please note that many journal articles are now available online. Regardless of the format (paper or electronic), these are still considered journal articles and should be cited as such. DO NOT cite electronic journal articles as though they were web pages!
APPENDIX C: A FEW TIPS ON STYLE AND ORGANIZATION

As you have learned, scientific papers follow strict formatting rules. Effective scientific writing, however, depends not only on the format and content of your paper, but also on the overall clarity and organization of your presentation. Good writing, regardless of the topic, is a skill that must be practiced and developed over time. Here are a few tips to help focus your efforts:

**Tense**
A scientific paper is a report about something that has been done in the past. Most of the paper should be written in the **PAST TENSE** (was, were). The present tense (is, are) is used when stating generalizations or conclusions. The present tense is most often used in the Introduction and Discussion sections of papers. The paper should read as a narrative in which the author describes what was done and what results were obtained from that work.

**Voice**
Scientific papers are often written in the **passive voice**; e.g., "Six petri plates were prepared." Some authors use the **active voice**; e.g., "We prepared six petri plates." Whichever approach you choose, be consistent throughout the paper.

**Usage**
Language is fraught with grammatical challenges--using words properly is the hallmark of a good writer. The separate handout "Biology Writer's Usage Manual" provides several tips that will help polish your grammatical skills.

**Clarity and Organization**
Beginning writers often build papers by writing sentences that are then strung together into (sometimes long) paragraphs. This "bottom up" approach to writing usually results in a paper that is a series of disjointed points. A better strategy is to utilize a "top down" approach in which you first organize your major points in a logical fashion. Each point is then developed into a series of paragraphs, and each paragraph is developed into a series of sentences. You can facilitate this process by beginning each paper with a thorough outline!

**Spelling and Punctuation**
This should be self-evident. Nothing detracts from an otherwise good paper more than sloppy proofreading!