Specific Types of Writing in the Sciences

*I write entirely to find out what I'm thinking, what I'm looking at, what I see and what it means. What I want and what I fear.*

Joan Didion

Writing in the sciences takes many forms. Here we consider specific types of writing that you are likely to encounter in your undergraduate science classes. If you go on to become a scientist, be it in academics or industry, or a physician, you will constantly revisit these various forms of writing. For each, we provide an overview as well as detailed instructions. These instructions are meant to provide a general guide; you should follow the specific instructions you receive in assignments that you have for class.

The following types of writing are discussed below:

- Short Answers
- Laboratory Notebook
- Research Paper
- Research and Grant Proposal
- Review
- Critique of a Scientific Paper
- Writing for the General Public

**Short Answers**

We begin with a form of writing that you will encounter many times as a student, but less frequently, if at all, as a practicing scientist: the short answer or essay form. This
type of writing comes up on many of the examinations of the introductory sequence of biology classes in college, so it is worth at least a brief consideration here. In some ways, this is the simplest form of writing; you are asked a direct question and given a limited amount of time and space to answer it. The questions are not usually open-ended, but instead are direct and straightforward. At the same time, writing short answers can present a special challenge. Sometimes, it is harder to write a brief answer than to write at greater length. In a short answer or essay, words must be chosen carefully and consideration must be given to what to include and what not to include. This takes some practice and thought.

When answering a short answer question on an examination, one of the most important points is to make sure you are answering the question being asked, not the question you hoped would be asked. For example, if the question asks to compare and contrast elements of mitosis and meiosis, the answer should do just that, *compare* and *contrast*. Consider this example of a student answer:

*Mitosis and meiosis are both forms of cell division. While mitosis produces two identical daughter cells from a single parent cell, meiosis produces four haploid cells from a single diploid cell. The different products of the two forms of cell division result from a difference in the mechanics of the two processes. In mitosis, a single round of DNA synthesis is followed by a single round of chromosome segregation. By contrast, in meiosis, there is a single round of DNA synthesis followed by two rounds of chromosome segregation. It is also important to note that the products of mitosis are genetically identical to each other and to the parent cell, while the products of meiosis are genetically distinct as a result of chromosome segregation and crossing-over, two processes that lead to genetic diversity.*

This answer nicely compares and contrasts the two processes; it puts the two side-by-side and discusses similarities and differences in a thoughtful manner. Now consider this response:
Mitosis is a form of cell division that produces two daughter cells from a single parent cell. It consists of the following steps: Interphase, Prophase, Metaphase, Anaphase, Telophase, and Cytokinesis. The resulting cells are genetically identical to the parent cell. An example of mitosis is the cell division that occurs as a fertilized egg divides to produce all of the cells in the body. Meiosis is a form of cell division in which four cells are produced from a single parent cell. There are two rounds of cell division and only a single round of DNA synthesis, so a single diploid cell produces four haploid cells. Genetic diversity is produced by crossing-over.

Notice that this answer is accurate and correctly describes the two processes, but leaves the comparing and contrasting to the reader. As a result, it does not really answer the question being asked. The student has conveyed information, but has not processed it or even answered the question. So, in short, if the question asks for a list, provide a list; if it asks to discuss, discuss; if it asks to compare and contrast, be sure to consider similarities and differences.

In addition to answering the question, be sure to present all of the relevant facts. Normally, an instructor is looking for a set of key terms or ideas and it is up to you to convey all of them. Sometimes it is useful to first jot down key thoughts or terms before you begin to answer the question, as a kind of checklist to yourself to be sure you are including all of the major points.

While your goal is to present all of the relevant facts, this does not mean to present everything you know about a subject. Stick to the relevant facts; do not include superfluous or unnecessary information. If what you write is not relevant to the question, you will not receive extra credit, and it if is irrelevant and incorrect, you may lose points. Answering questions on an examination is not just an exercise in conveying information, but also a chance to demonstrate that you are able to read and answer questions.
**Laboratory Notebook**

Many of your science classes have a laboratory component. Laboratory exercises are designed to give you hands-on experience with techniques and to illustrate some of the concepts that are introduced in lecture. This is also the place to learn to ask questions, develop a hypothesis, design or carry out an experiment to test the hypothesis, collect and analyze data, and present your work.

Central to the process of doing science is the keeping of an organized and thorough laboratory notebook. In order to become a good scientist, you must learn how to keep an accurate and current record of all experimental procedures, observations, and results. Your notebook is your own personal reference when writing a formal report or article on the experiments you have performed.

When you keep a laboratory notebook, you also leave behind a legacy once you leave the laboratory. Anybody who follows in your experimental footsteps should be able to go to your notebook and, without additional references, repeat every single experiment reported there. In fact, when you work in a research laboratory, your notebooks are the property of that laboratory and you are legally responsible for their contents.

The keeping of a laboratory notebook is a very important form of scientific writing and in some ways can be thought of as the cornerstone of all other types of writing. There are various forms of writing that you will learn about in your biology courses at Harvard, but all of them build on the critical skills of effective communication, organization, and data interpretation that are first practiced in the laboratory notebook.
General Laboratory Notebook Techniques and Practices

• Laboratory notebooks are bound books, with numbered pages that cannot be removed from the book (i.e., a 3-ring binder with loose leaf paper is not acceptable). Two examples are the Student Lab Notebook with Spiral Binding, with 50 carbonless duplicate sets, from Hayden McNeil Specialty Products and the National Brand Laboratory Research Notebook distributed by AveryDennison Office.

• Inside the front cover and on the table of contents page, provide descriptive and identifying information: your name, e-mail address, university, course number and title, laboratory room number, and teaching fellow.

• Do not remove any pages from your laboratory notebook. Original, consecutively numbered pages must always remain.

• Do not skip pages. If a page is accidentally skipped, draw a diagonal line through it.

• Because laboratory notebooks often have duplicate pages, write only on the front side of each page.

• Write in black or blue ink. Do not use pencil.

• Do not make erasures or heavy scribble outs, or use white-out. If you need to change something, draw a single line through it and write your correction on the next line. Nothing in your notebook should be obscured.

• Update the table of contents each time you use your notebook.

• Start the documentation of each new experiment on a fresh page.
• During the laboratory period, carry your notebook with you wherever you go and enter data or observations as you have them. Do not write information on scraps of paper and enter it into your notebook later.

• Photographs, computer printouts, and other data generated by something other than your pen should be taped into the notebook. A photocopy can be taped to the duplicate page.

• When an experimental write-up is completed, sign and date it. Cross out any remaining space on the last page with a single diagonal line.

• Use continuation notes when an experiment requires more than one page. At the bottom of each page, write “continued on page ___”; at the top of each page, write “continued from page ___”. This is particularly necessary when a single experiment is not documented on consecutive pages (which often happens when a new experiment is started before an ongoing one is finished).

• Write legibly.

Format for the Laboratory Notebook

Laboratory notebooks often follow a particular format, which is described on the following pages:

**Table of Contents**

Every experiment in your notebook must be documented in the table of contents. The first page of a notebook is typically reserved for the table of contents, but some,
including the ones recommended above, have a table of contents page already included.

In your table of contents, record the following information:

- the number and title of each experiment;
- the date when the experiment was started;
- the page number where documentation for that experiment begins.

**Date**

At the top of the first page, record the date the experiment was performed. Each subsequent page should also be dated. On the first page for that experiment, write out the full date (month, day, year). Subsequent new pages used with that same date can be dated at the top using an abbreviation (X/X/XX). In either case, place the date close to where the page number is located. If an experiment is carried out over several days, it must be clear which steps in the procedure were carried out on each date. You may put a range of dates at the top of each page, and then indicate within the write-up (in Notes and Changes to Procedure section) what was done when.

**Number and Title of Experiment**

The number and title of the experiment should be written at the top of the first page of an experimental write-up. The title should be descriptive, but not too wordy. Examples of good titles include “Observing Mitosis and Meiosis” and “Complementation and Meiotic Mapping in *Saccharomyces cerevisiae*.”

**References**
Reference any source you used to prepare for the laboratory. You will definitely need to reference the laboratory manual, and you may also want to reference the textbook or any other source of background information you used. Here are two examples:


Collaborators

Acknowledge the contribution of your laboratory partners by including their names in this section.

Purpose

In this section, you are explaining why you are performing the experiment and how you will do it. Not only is this section useful to others who may want to replicate your work, but it can also be tremendously helpful to researchers when they are reviewing their own work. In one paragraph, succinctly convey the goal of the experiment or the experimental question, why the experiment is being performed, how the experiment will be carried out (methods or techniques used), and any relevant background information. If relevant, also briefly discuss possible outcomes. This section should be no more than a half of a page.

Materials
List equipment and supplies, reagents and chemicals (even water), names of organisms used and their strains or genotypes. Also include the manufacturer of a reagent or supply if a particular item can only be obtained from that company—e.g., Ready-To-Go PCR Beads (Biorad).

Planned Procedure

In this section, present the procedure that is outlined in the laboratory manual in your own words. Do not copy blindly. List in step format. The steps can be brief, but must be descriptive enough for someone to be able to follow your directions. Also include helpful notes (wear gloves, keep tube on ice, perform this step in the hood).

Pre-laboratory Exercises

Some laboratories will have pre-lab questions or exercises (found in the laboratory manual); present your work here.

Notes and Changes to Procedure

This section is completed during the laboratory period. Note any deviations from your planned procedure. Also make notes and observations pertaining to the experiment and anything that you think is important to note about what happened or what you saw. Remember, someone should be able to read your notebook and do exactly what you did, not just what was listed in the laboratory manual. Be sure to make note of mishaps or anything that you think may affect your results. Always make clear the part in the procedure to which you are referring. Here are some examples:
• Step 1 was already completed by the teaching staff before the laboratory period.
• When loading the molecular weight markers in the gel, 20 ul was loaded, not 10 ul as written in step 4.
• This group’s yeast plates were contaminated with bacteria so another set was used (supplied by J. Watson and F. Crick).
• Step 5: agarose gel was run for 45 minutes at 100 volts.
• For step 6, 53 colonies were identified and streaked to the master plate.

Do not forget to include what happens to your experiment in your absence:
• The TF incubated the plates at 30°C and then transferred them to 4°C after 24 hours.

Results

This section should include any raw data that you produce during the laboratory period, such as tables of yeast spore genotypes, charts of color changes of samples, photographs, drawings of observations. Anything presented in the results section should be labeled with a descriptive title and measurements should always be labeled with appropriate units. Do not forget to make a copy of any photograph or drawing to put on the duplicate page.

Data Analysis

This section will include any calculations, manipulation of the data, or conclusions that you make after the laboratory period. Items that might be found in this section include a table of molecular weight vs. distance migrated and accompanying
graph, calculations \((\text{Chi} \text{ square test})\) and determination of linkage, or identification of unknown strains based on information presented in the results section. Again, do not forget to include titles, all appropriate graph labels, and units of measurement.

**Discussion**

In this last section, evaluate and discuss the success of the experiment. Write as if your audience is someone who wants to repeat your experiment, or someone who wants to move forward from your experiment (this could be you, at a later date). What does that person need to know? Include interpretation of your results—how you came to the conclusions presented in the previous section and whether or not your conclusions agree with any of the outcomes discussed in the Purpose section. What did you learn from the experiment? If the experimental outcome contradicted expected results or produced surprising results, suggest possible reasons or address possible sources of human or equipment error. Keep in mind that just because an experiment does not give expected results does not mean that the procedure or the execution of it was flawed. Unexpected results can be real and can lead to alteration of current models and ways of thinking (but only if someone else can read your notebook and repeat your experiment). Also in this section, address any questions posed in the laboratory manual.

**Signature**

When you complete each experimental write-up, sign and date your work. Put the date that you did the calculations and finished the work, not the date you did the
experiment (this should already be documented in your notebook). Cross out any remaining blank space on the last page with a diagonal line.

**Research Paper**

A research paper is the currency, the mainstay of scientific information. This is the place where new results and ideas are communicated to other scientists. Most of the facts you learn in a science lecture or textbook are actually interpretations of data that were first described in the form of a research paper.

A research paper is essentially an argument. In a research paper, the authors put together various observations and pieces of data to come to some sort of conclusion. It is written for other scientists, but, because science encompasses many fields, is often written in a way that can be understood by someone educated in science though not necessarily in the field under study.

The format, style, organization, and level of detail of research papers vary depending on where they are published. Some journals, such as *Science* and *Nature*, emphasize short papers without a lot of primary data. Others, such as *Cell*, *Genetics*, and *Genes & Development*, are more complete and thorough. In addition to differences in length, the organization of the papers varies depending on the journal. The format described below is a generic one that is presented as a way to consider each part of a research paper. The particular format you follow will depend on the nature of the assignment you have or the journal to which you are submitting a paper.

As a student, you will often be asked to write a research paper as a way to put together experiments that you did and data you gathered as part of a laboratory exercise
or a series of laboratory exercises. Note that this type of assignment is different from the laboratory notebook (see above). While the laboratory notebook emphasizes careful note taking and observations, the research paper is a chance to make an argument by synthesizing other studies and your own experiments.

A research paper has several sections, which are described here:

**Title**

The title of a research paper should be concise; at the same time it should contain enough information that a reader can determine the relevance of the paper to their needs without reading the entire paper. In reports of an experimental nature, the specific information given in the title should include the factors being manipulated and the effects of responses being measured. An example of a self-explanatory title containing the above three elements would be, “Ultraviolet light induces apoptosis via direct activation of Fas/APO-1, independent of CD95L.” Avoid cryptic titles such as “A Lab Report” or “Enzyme Action.” Such titles give little or no information as to the content of the report.

Another way to think about a good title is to put yourself in the position of a researcher who is going to search a database of scientific literature (e.g., PubMed) using key words to find articles of interest.

**Authors**

When considering authorship on any paper, the contribution of ideas, materials, experimental results, and the work of writing of the article must all be taken into consideration. In the case of a research paper based on experiments you do as part of a
laboratory exercise for a class, you are the first author by virtue of doing all the writing and a large amount of laboratory work to produce the data. The second author is your laboratory partner. The last author on your paper is your TF, acting as the Principal Investigator. The other students in your section have provided additional data for your article and thus should be after your lab partner and before your TF, as scientists who have collaborated in your efforts.

Abstract

This portion of your article should be a summary of your entire report. Without including specific details or references to figures or other studies, provide background, state the principal objectives of your study, describe the methods used, list your most important results and state what you can conclude from them. Similar to the research paper itself, the Abstract should ask and answer a question. In addition, it should be able to stand on its own as a summary of the research; if the rest of the paper were missing, the abstract should still be comprehensible to a reader unfamiliar with the study.

Although it comes first, the abstract should be the last thing you write, which will allow you to simply extract key points that you have already written in the body of the report and will ensure that you do not include any information in the abstract that is not in your research article. An abstract is typically between 150 and 500 words in length.

Introduction

The Introduction should provide a context for the topic under study and give the reader the background necessary to understand the rest of the report. As a result, the
background will usually be based on previously published material (which must be properly cited). In addition to establishing the context of the problem, the Introduction should provide a concise statement of the problem or goal of the project and a description of the experimental approach(es) used to answer those questions.

Note that an Introduction differs from a Review of a particular topic. While a Review typically covers a topic in detail, the goal of an Introduction is to provide context to understand the question you are asking or the system you are studying. In essence, the Introduction should build to your experimental question. This can be done by describing what is known about a particular topic, to be sure that the reader understands the system, but also considers what is not known or where there is room for additional work.

Materials and Methods

This section describes the specific details of your experiments. As a result, it must provide enough information about the techniques you used to allow the reader to both judge whether the data justify your conclusions and, if desired, replicate your experiments. It is always written in the past tense, as it describes exactly what you did. For example, “The plates were incubated overnight at 37°C.”

This portion of a research paper is usually divided into sections labeled with the appropriate subheadings to indicate a specific method (i.e., PCR or Western Blotting). Usually these subheadings are arranged chronologically based on the order of the experimental results presented in the Results section. DO NOT present/discuss your results in this portion of the article, it is meant to be a “how to” guide to your experiments.
How much detail is required? You should provide sufficient detail so that a reader could order the materials you used and replicate the experiment. If a published account is already available (for example, bacterial transformation, PCR, sequencing), the technique itself need not be described in detail again, but you must provide enough information about how you performed the experiment so that it can be independently replicated in another laboratory (for example, in a discussion of PCR, you must provide information about the primers and thermal cycling conditions used, but you do not need to describe how PCR is done). In addition, for all experiments, the name and manufacturer of reagents (including enzymes, bacterial strains, kits, columns, etc.) and relevant instrumentation/equipment must be provided. This section should also include sample sizes or number of replications, strain and plasmid names, and other factors known to affect the particular experiment (e.g., temperature, pH, etc.).

Results

In this section, you objectively present the results of your work through descriptive text, figures, and tables. In essence, you are reporting what you observed in each experiment. Briefly state what you did in the experiment, leaving out the plethora of details you included in the Materials and Methods section, describe the key result, and indicate the figure or table containing the supporting data. Remember that the essence of good scientific writing lies in its organization and the distillation of critical results. Refer to the figures and tables parenthetically. This will help you avoid bogging down your writing with a lot of extra words and it will help to keep the reader focused on your key points. In addition, you should avoid explaining every detail of every figure. It is far
better to direct the reader to a specific portion of the figure that gives the best
demonstration of what you claim is your result. The first one or two sentences of each
new paragraph/portion of results should be a transitional statement that explains the logic
of why, based on the last experiment, you went on to do the next experiment. Finally, you
should avoid drawing conclusions or inferences about the results in this section; save that
for the discussion.

*Figures and Tables*

Figures and tables provide ways to display primary data, such as a photograph of
a gel or a Southern blot or a list of numerical data. Each figure and table should be
accompanied by a legend. A well-written legend provides enough information about the
figure or table that the expert reader (for example, a scientist in a related field) could
understand the experimental results by simply looking at the figure or table and reading
the legend. In other words, figures and tables are independent units that can be
understood without reference to the text. Try this out by going to any journal article and
“reading” it by simply glancing at the figures and tables. Note that every figure and table
should be referenced in the text.

*Discussion*

This is the portion of your article where you interpret the results in the context of
what is known in the field. The first paragraph should summarize what you believe to be
your most important results and what you believe are the best conclusions based on your
findings. Then, you may go on to discuss those conclusions in the broader scientific
context (i.e., compare them to what has been reported by others in the same area of biology). Discuss the implications of your data and propose future experiments to address unanswered questions. It is important to acknowledge deviations in your data, compared to the results you expected, and explain why those deviations may exist.

References

This final section lists all of the references you cited in the research paper. Every paper you cite in the text should have a corresponding reference in the References section and vice versa. The specific format of the in-text citations and the references listed in this section of the research paper varies depending on the particular journal or assignment.

Two rules of thumb always apply, however:

- Follow whatever format is suggested or required. This ensures that the references are formatted in a consistent fashion throughout your paper.
- Watch the details of the suggested format. If a comma is written after the volume number, this means that a comma is required, not a colon, not a semicolon.

Additional information about citing references can be found in Chapter III.

FAQs on Writing Research Papers

Q: What is the difference between the Results section and the Discussion section?

A: The answer is in the R and the D. R = report your results in the Results section. You should not present any interpretation or draw any conclusions in this portion of your article. D = discuss your results in the Discussion section. This is the appropriate section
to make conclusions and state your interpretation of the data you have presented. It is your job to consider all possible interpretations before presenting one, which you think, is the best.

Q: What is the appropriate length for each section of the article?

A: The abstract is the only section that has a pre-defined length, but often there is a word limit for the article as a whole.

Example:

If the word limit is 9,000, the lengths of each section may be something like the following: 300-400 words in the Abstract, 1,400 words in the M&Ms, and 1,000 words for your references. This gives you a remainder of ~ 6,000 to use for your Introduction, Results, and Discussion. As a rule of thumb, these sections should be about equal lengths, leaving you 2,000 words for each.

Q: What types of materials do I need to cite in my reference section?

A: All printed material that you use as a resource to produce your research paper should be included in your references. This includes your class sourcebook, websites, review articles, books, and all primary research literature.

**Research and Grant Proposal**

A research or grant proposal is one of the more difficult kinds of writing assignments you will encounter as a student. In addition to understanding the basic components of a research paper (described above), a research proposal
requires an additional step. It requires that you ask an original question, develop a reasonable hypothesis or hypotheses, and then come up with a plan for testing that hypothesis or set of alternative hypotheses in the form of an experiment or a series of experiments. If you are writing a real grant proposal, you will eventually do the experiments you describe. If you are writing a research proposal for a class, you are usually not expected to do the experiment or collect any data. Nevertheless, the feasibility of the proposed project is often considered in the evaluation of any proposed project.

If you are writing a real grant proposal, it pays off to do some research into the kinds of proposals that are successful with a particular funding agency before you start thinking of the questions that you would like to answer. Some agencies give high points for novelty and creativity while others may prefer proposals that are sound but low-risk. This information may be easily obtained from your advisor or by contacting successful applicants. Usually, these individuals are very helpful and will answer any questions you may have. You can ask to read some of their past proposals. Unless there is a conflict of interest, most grant awardees will be very open to sharing information.

A major challenge of this type of assignment is coming up with a question. This step is difficult because the question has to be one that has not been asked before or one that not been fully answered. In addition, the question has to be answerable in the context of a feasible experiment or a set of experiments. Fortunately, there are places to turn to for help. Keep in mind that questions do not come out of a vacuum. A good place to start is your advisor. A
knowledgeable advisor with expertise in a given field of science will be an invaluable source of guidance. This person can direct you to the questions that are currently unanswered within a particular field. Alternatively, he/she may suggest areas of study that have received little or no attention and therefore make them ideal for a proposal. If you prefer a more independent approach or if you are writing a proposal for a class, you can read several papers in your field of interest before coming up with a question. Most papers suggest follow-up experiments in the discussion section. Another good source for a good question is a current review paper. Reviews are written by experts in a given field and they often suggest areas that need more study or questions that remain to be answered.

The format of a research proposal is very important, especially if you are submitting it for funding. Every funding agency expects that submitted proposals be formatted in a very specific way. These guidelines are strictly enforced. A funding agency will turn down a proposal that is not properly formatted. You will also loose points from class assignments if you have not followed directions for the layout. Therefore, be sure to follow whatever guidelines are given to you for a class assignment or for a granting agency.

The text of a research proposal is typically double-spaced, written in a 12-point standard font (Times Roman, Century), 15 cpi (characters per inch), with one-inch margins on all sides.

Make your proposal reader-friendly. You may occasionally use bold or italics to highlight important points. Use headers to organize your proposal. You
should indent paragraphs, and unless absolutely unavoidable, skip a line between paragraphs.

The final proposal is comprised of several sections including the following:

- Title Page (optional)
- Abstract or Summary
- Hypotheses and Aims
- Background and Significance
- Preliminary Results (if any)
- Detailed Aims (research design and methods)
- Anticipated Results
- References
- Appendices

The sections in a proposal are distinct from those in a research paper, and these will be discussed in more detail below.

Title Page

Proposals for class assignments often require a Title Page. The Title Page contains the title as well as identifying information, such as your name, campus address, and contact information. The Title Page for most funding agencies is given in a pre-printed format where you need to fill in your information. For both kinds of proposals, the title should be a clear, concise, and accurate description of
the goals proposed, while containing enough information so that a potential reader can get the main point of the proposal. As examples, consider these three titles:

**Effective**

- *The Process of Nuclear Import Requires Recognition of a Nuclear Localization Signal by α-Importin*

**Not Effective**

- *Importins Assist Entry into the Nucleus*
- *How Proteins Enter the Nucleus*

Only the first one is specific and direct enough to alert a potential reader to the subject of the paper.

**Abstract or Summary**

In the Abstract, key elements of the paper are mentioned. It should serve as a proposal “advertisement;” that is, be simple, interesting and accurate. In the Abstract, you should do the following:

- provide context for your proposal;
- introduce the model system you will be using, and why it was chosen to answer the questions proposed;
- state your hypothesis.
- outline your aims and briefly describe the experimental methods to be used and expected results of each aim.
• explain the relevance of accomplishing the proposed research and how it fits within the larger picture. In other words, how will your research affect other areas?

The Abstract or Summary should be able to stand on its own without reference to the rest of the Research Proposal. Typically, there is a word-limit for this section, such as 250 words. Although this section appears first to the reader, it is best to save writing it until the end. A good Abstract reflects the entire proposal.

**Hypotheses and Aims**

It is a good idea to introduce the reader to your hypotheses and aims as early as possible. This section should be brief (one-half to one page long). Funding agencies are increasingly requiring that proposals be hypothesis-driven. Even if what you are proposing to do is more of an exploratory nature (such as a genetic screen or microarray experiment), you should frame it within the context of a testable hypothesis. Your hypothesis should guide the research. Consider the examples provided below. In the first example, the hypothesis is clearly stated. In the second, it is less clear; after reading it, the question remaining is “why?” You should be thorough and state your hypothesis clearly.

**Effective**

*I propose to use molecular systematics to test the hypothesis that two species of the Pan troglodytes clade (P.t. troglodytes and P.t.verus) are able to interbreed successfully.*

**Not Effective**

*I propose to study the genetic and environmental determinants for key pathways of folate metabolism during human development.*
You should also include your aims or goals in this section. Your aims should each have a brief description (1 or 2 sentences) of the methodology you propose to use and how the results will be used to test the hypothesis. The number of aims is usually dependent on the amount of time needed to complete the entire project. Short proposals (i.e., summer research) should have one or two aims. Longer proposals (1-3 years) can have up to 3-4 aims. All aims should be related to the hypothesis, and they should be attainable and within your expertise level. You may choose to draw attention to your hypothesis and aims by highlighting (indent or use italics) those sentences. Most reviewers will greatly appreciate this time saver.

*Background and Significance*

This section provides context for the research by providing background information on the questions being addressed. This section requires a good and succinct literature review. Include appropriate citations and all relevant information. You should state the rationale behind your proposal and why it is important to answer your specific question. The length of this section varies. If you do not have preliminary results of your own, this section should highlight any research done by others that supports the rationale of your proposal. For short proposals (1-2 pages), this section can be brief and included in the above overview.
Preliminary Results

When available, include work you may have done that is relevant to the project. In this section you may include Figures and Tables that show your work. You should refer to the figures within the text (e.g., Figure #). The purpose of this section (when available) is to support the feasibility of the proposed project.

Detailed Aims

Include here the specific methods you will use to accomplish your aims. Describe here the experiments you will need to carry out to accomplish your proposed goals or aims. Also describe the logic and design behind each experiment proposed. You should include enough detailed information for the reader to understand the methodology, but do not give excessive information (i.e., materials used). Consider your experiments carefully – does it really test the hypothesis? What will the outcome tell you? If proposing a new approach, discuss why it improves on current methods used. Try to identify any pitfalls in your experiments and discuss how this will be circumvented.

Example of a Detailed Aim

I propose to use both nuclear and mitochondria DNA to analyze polymorphisms characteristic to each group. This will be done using hair samples from P.t. verus and P.t. troglodytes from wild populations.

Anticipated Results

The name of this section sometimes misleads students. Under this heading, you should consider all of the possible outcomes of your study, not just those you anticipate. In other words, you should consider all the outcomes that you are able to anticipate. The
point of this exercise is to think through the design of your experiment. Will your experiment give outcomes that are interpretable? How likely is each of the outcomes? For each possible result, you should discuss how you would interpret it and how it would allow you to discriminate among your hypotheses. Will you be able to meet the goals you set out in your Introduction?

In addition, you should consider how your anticipated findings would change the way we think about the topic and how they fit in the context of the field. This is also the place where you should address potential shortcomings or limitations of your proposed study. You are also welcome in this section to speculate on the generality of your findings and suggest new or follow-up questions or experiments that might stem from your work.

Alternative methods should be included for experimental approaches that may appear risky (not been previously used). It is particularly important to provide alternative methods when the outcome of any aim (*i.e.*, protein purification) is a prerequisite to others (*i.e.*, characterization). The description of the alternative approach should not shadow the initial method proposed. Instead, it should be included as a concise description that strengthens the viability of the project.

*References*

Provide a reference for each in-text citation. Be sure to follow the suggested format. If not specified, the use of numbered citations is recommended to save space.
Appendices

Any supplemental material, such as photographs or enlarged figures, should be included in the Appendix. Do not use this section to include essential material not included in the proposal because of a page limit. Include tables and figures only if they add to or complement the descriptive text. For example, a figure is sometimes useful to describe a complicated experimental apparatus or biological model. A table is sometimes helpful if your experiment has many variables or many possible outcomes. Tables and figures are placed in that order at the end of the document, after the References.

A Few Final Tips about Research and Grant Proposals

Be objective in your language: test hypotheses, do not try to prove them. Discuss your paper with classmates or anyone who is willing to listen. Talking about your ideas often helps to clarify them and others may catch errors that you might have overlooked. In addition to consulting published materials, feel free to talk to experts in the field of your proposal, whether they are from Harvard or elsewhere.

You should edit your proposal after you have completed the entire first draft. Editing a proposal before submission is essential. When submitting a proposal to a funding agency, get feedback from different mentors. You want to receive feedback in every aspect of the paper, including the science, grammar and organization. Be open to receiving criticism; this will only improve the quality of your final proposal. You should reply graciously to all reviewers’ comments and address their concerns if resubmission of the proposal is necessary.
Review

A review gives you the opportunity to explore a topic in depth. You get a chance to read the primary scientific literature, teach yourself a topic, synthesize information, and put it all together in the form of an essay. Some students mistake a review with a book report, thinking that the point is simply to report what is known about a given subject or to summarize four or five journal articles in a given field. This is not the case. A review is in fact a creative exercise. A good review not only conveys what you have read and learned, but also takes the next step and comes up with an angle or argument that extends what you have read. What does it mean to take the next step? In this case, it means to evaluate what you have read, synthesize information from various sources, and then come up with a new way of looking at a field. You may put together information in a new way, compare and contrast different pieces of information, explore relationships, or analyze and evaluate primary data. Whatever you choose to do, you should try to analyze and evaluate, not report and list.

Your goal, in other words, is to make a point, to come up with a thesis statement. A thesis statement is simply an argument that you propose and then use evidence to back up. You will recall working on thesis statements in Expos. The thesis statement here is no different. It is a chance to make an original proposal or argument. The strength of this argument will depend on your ability to back it up with evidence from the literature, anticipating and responding to potential objections and counter-arguments, and the organization and structure of your writing.
Coming up with a thesis statement is not easy. You normally begin with a topic, something you want to explore, not a thesis statement. As you read articles and learn about your topic, start taking notes:

- Is something not clear to you?
- Do different authors report conflicting data?
- Do you think it would be interesting to bring together two areas that were previously thought to be unrelated?
- What is particularly interesting about a given topic?
- Is one approach radically different from another?
- Are there assumptions that run through many different experiments?

The answers to any of these questions can serve as a germ of a thesis statement.

Of course, to be convincing, you have to find support for your thesis statement. Be sure that for the angle you choose to take, you can support it with examples from the primary scientific literature. Remember, your goal is to try to convince your reader of the point you are making, and you cannot convince your reader without a good deal of evidence.

A review gives you the opportunity to read papers from the primary literature. This is not an easy task and is therefore discussed more fully in Chapter VI. Reading primary research papers can be difficult, but it is an essential part of being a scientist. It is in a research paper where primary data are reported. You should begin to get used to looking at primary data yourself and coming up with your own interpretations. After all, this is the task of a scientist. What you read in a textbook, what is presented in lecture, what is discussed in a Discussion section of a paper is the result of a distillation process.
Someone has looked at the data and come to some kind of interpretation. While most data are real and objective, interpretations are not. Reading the primary scientific literature gives you the chance to look at data for yourself and form your own opinions and interpretations. Were the experiments well designed? Is there an important control that is missing? Were the experiments replicated a sufficient number of times? Are the conclusions sound? Do the interpretations go beyond the data? These are the types of questions that you should be asking yourself as you read the primary literature.

Writing a good review, then, relies on the two aspects of writing that were emphasized in Expository Writing: argument and evidence. You should begin such an exercise by choosing a topic and then researching it. After reading several papers, see if something stands out or might work as a thesis statement. Keep reading and find out if your thesis statement holds up. Then begin writing. Some people like to begin by writing an outline to organize all of their thoughts and information. Others prefer to write quickly and then go back and carefully revise their work. Whatever your approach, you will want to pay particular attention to the first paragraph, in which the direction of your paper and the nature of the problem you want to address are clearly stated. Once you state your case, you will want to support it and build it carefully. Use the information you have collected to make a point, to build an argument.

One way to think about a review is like taking a photograph. When you take a photograph, you are looking at something that is already out there and capturing it on film. While the resulting image is a representation in most cases of the real world, the photographer does play a creative role. The photographer chooses what to include and what not to include, how to frame the image, what to bring to the foreground and what to
place in the background, whether an image is clear or out-of-focus, the amount of light
and darkness. In a similar way, the reviewer takes what is out there and distills it through
his or her own writing to create something new and original.

**Critique of a Scientific Paper**

A common assignment in an undergraduate course involves reading one or two
papers (either a review and a primary paper, or two primary research papers) and then
writing a critique. When dealing with all of the data and details presented in a primary
paper, it is very easy to write an unfocused, poorly structured paper!

When writing a critique, it is essential that you write your paper as if you are
giving a presentation or lecture about the topic. You probably would not begin a lecture
with a critique of the methods used by a particular research group. Instead, you would
likely start by providing some broad background information, strategically working your
way into the details of your presentation. If your presentation included a critique of the
work, you would present the critique only *after* having provided a solid foundation for
understanding your critique. And of course, you would end with a well-crafted

You should structure your paper similarly. Begin with a broad introduction: what
is the overall field or topic being addressed? What specific question(s) are the authors
investigating? What is the main hypothesis of the authors? Continue with your written
presentation, describing how the authors test their hypothesis (what is their experimental
approach?). Only include specific details about the methods if those details are later
necessary for the reader to understand or evaluate a specific point you wish to make.
Writing for the General Public

Writing for a general audience, sometimes called science journalism, presents a special challenge. While a full discussion of this important area is beyond the scope of this Guide, we include a brief consideration of this type of writing here for a few reasons. First, you are likely to encounter at least one such writing assignment as an undergraduate science major, so having a few pointers might be helpful. Second, writing for a general audience can help you sharpen your thinking skills and, in the process, your writing skills. After all, if you can explain a result or research paper to someone else, you probably understand it well. Third, and perhaps most importantly, keeping lines of communication open between scientists and nonscientists is becoming increasingly important as such issues as stem cells, cloning, nanotechnology, global warming, and the like enter the public arena. In this way, writing for a general audience can be thought of as less of a task and more of a responsibility of scientists.

There are aspects of writing for a general audience that are shared with other forms of writing. For example, writing for a general audience requires that you know your audience. At times you need to understand how to summarize, at times simplify, at times explain to get scientific ideas across. You need to understand when you can avoid technical language, as well as when a key term cannot be left out but needs to be explained. You need to understand what background you need to provide and what knowledge can be assumed. Knowing your audience is a key aspect of any sort of
writing, even research papers. In this case, you need to keep in mind whether your audience is general, from any field of science, such as when you write for journals such as *Science* or *Nature*, or more specialized, as is the case for readers of *Genetics* or *Animal Behaviour*. The kind of words you use and the amount of background your provide will vary depending on who you expect to read your paper.

In addition, writing for a general audience is an excellent exercise in summarizing. Often we are asked, when writing for a general audience, to explain an exciting new result or discovery. To do this, we need to fill in the background, describe the key experiment, and convey the major result, all in a relatively small amount of space. Understanding what to include and what to leave out and how to simplify a complicated idea or apparatus is often key to a good piece for a general audience.

While there is no one way to write for a general audience, there is a certain style that often shows up in this form of writing. For example, the paragraphs tend to be short, shorter than you are probably used to in scientific or expository writing. Technical words are often avoided. Important terms that cannot be avoided are carefully explained. Finally, writing for a general audience often begins with a “lead” or “hook,” something that is written in a way to grab the reader. For example, the hook may be a simple, dramatic statement of a finding, a narrative, or a twist or surprise from what is expected. However you open a piece for a general audience, and however you write it, you will want to keep the piece moving and your reader interested. Try not to get bogged down in technical explanations or lengthy descriptions, unless it works for the story you are telling.