There are many books devoted to writing in general, and to scientific writing in particular. This is to give you ideas about what scientific writing is, and a simple plan for how to do it. Early on, you may be writing a lab report or a term paper for a course. Later, you may want to submit a manuscript to a journal for publication, or apply for a scholarship or a job. Remember, there are many books on style and composition - here we are discussing the form and function of a scientific report.

The most important rule for any writing - think about your reader's needs.

What does this mean? Imagine for a moment, now, and then as you write and revise your report, that you are reading it for the first time. Is your information in a logical order? Are your sentences understandable and your paragraphs well organized? Have you described your ideas, results and analyses fully enough, or is there needless detail? Your goal is to teach your reader something, perhaps even to surprise or delight, but never at the end to puzzle or mystify.

Who is your reader?

For now, probably your professor, or your lab demonstrator. These readers will know a lot about what you are trying to say, but they need to see if you do. The easier your paper is to read and the more complete it is, the better your grade. Later, your reader may be a colleague, or another student, or maybe an editor or a potential employer. These readers might not know much about what you are trying to say, but you can assume that they are bright enough to keep up with you, if you give them understandable information in a sensible sequence. Here, ease of reading can mean better acceptance of your ideas, publication of your paper, or getting a scholarship or a job.

Regardless of your audience, a beautifully typed paper whose content lacks clarity or intellectual merit will not help you. A useful strategy is to have a friend (preferably more than one!) read a draft and make written comments on it. If they are puzzled by or unsure of your meaning, then assume you have not been completely clear. Rewrite unclear section(s), even if you think your draft-reader was just being obtuse. Your object is to make your thoughts generally understandable, and it is more likely that you could not see your writing objectively. A friend who takes the time to read your draft, and criticize it rigorously, is doing you a great service. So, be thankful when they point your errors and inconsistencies. Another strategy is to leave yourself time between drafts (ideally several days) so that your errors will be easier to detect yourself. This is not always possible, but it is more likely if you do not leave things to the last minute.

On the other hand, even the most brilliant ideas and prose will seldom be given their due if they are poorly presented. Whenever possible, type your reports and have them printed on a good quality printer.
Even neat handwriting is more difficult to read than type. It makes for a physically longer report and, since people1s script develops quirks (even if stylist or artistic) this requires an extra decoding step.

Since your goal is to make life easy for your reader, typed copy is close to essential. A typed report will not give you higher marks by itself, but anything that puts your reader into a better mood cannot hurt. Remember: your reader is likely to have dozens of papers to grade, and other commitments. Further, I recommend typing it yourself, for several reasons. Most people can type faster than they can write neatly, and those that cannot yet do so will improve with practice. Secretarial help is expensive, and is becoming uncommon even in many businesses. Word processors simplify editing, and most have spell check; the best also have grammar check.

When trying anything for the first time, there is no substitute for a good example. For report writing, you should consult scientific journals, to compare advice here with what scientific writers actually do. Notable for their clarity of format are biological journals like the Canadian Journal of Botany, and Canadian Journal of Microbiology.

Your scientific paper should be divided into sections, to organize communication of your work and thoughts to your reader. Most commonly these sections are (in order): Title, Abstract (Summary),
Introduction, Materials and Methods, Results (Observations), Discussion, and Literature Cited (References).

Title

The title might indicate the topic you will be discussing, for example: Lab 4 - Dependence of photosynthetic activity on wavelength of incident light. Or, it might summarize the take-home message of your paper, for example: *hyp* Loci control cell pattern formation in the vegetative mycelium of *Aspergillus nidulans*. Either way, the title gives your reader their first clue of your paper's contents, and sets up an implicit contract that your report must then fulfill. Currently, titles are often a one-sentence summary of the main message.

Abstract (Summary)

Although it is the first section, the Abstract should not be written until the rest of the paper is done because it is a brief summary of everything else. It should be understandable by itself, and briefly tell your reader the main messages in paper.

For example: Aspergillus nidulans grows by apical extension of multinucleate cells called hyphae, which are subdivided by the insertion of crosswalls called septa... This requires coordination between localized growth, nuclear division, and septation. I searched a temperature-sensitive mutant collection for strains with conditional defects in growth patterning. I identified six mutants... which I call *hyp* for hypercellular. Phenotypic analyses...of hyp mutants... suggest a mechanism for coordinating apical growth, subapical cell arrest and mitosis.

Here I described the experimental question, method and major conclusions, but without details. Note that unless the main point of the paper is to describe a new technique, the methods are seldom more than a sentence. The ellipses (...) show that I

have not reproduced the entire abstract here. Generally, scientific journals limit the abstract to 150-250 words.

Introduction

The principal functions of the introduction are to put your work into a general context and to define the particular question(s) you will address. First, you must provide a theoretical, practical, and/or historical background so that your reader will be able to understand what you did and why it was worth doing. Second, you must identify your particular topic.

The first part of the introduction is a minireview and so your statements must be supported by references. For example in the *hyp* paper, you would need to discuss what is currently known about fungal morphology and about nuclear division and growth controls, each time referring to published work. This can help you to clarify your ideas. You should be finding and reading appropriate references from early on, and jotting down ideas as you go. However, leave writing this section until after you have a good draft of the discussion. Your ideas about your work and its significance might change considerably.

The second part of the introduction is a "statement of purpose", which can again summarize the main message of the paper. For example, "Here I describe the characterization of ... five genes that appear to play roles in mycelial cell pattern formation... *hyp* mutants have abnormally short subapical cells...but can complete the asexual life cycle at restrictive temperature suggesting that they mislocalize growth cues that are required to establish wildtype mycelial growth patterns."

There are several methods for citing your sources in the text. One of the most common styles is called the "name-date" method. For example, Septa are formed with a uniform spacing along vegetative hyphae (Fiddy and Trinci, 1976), and septum formation is dependent on mitosis, nuclear positioning and attainment of a critical cell size (Wolkow *et al.,* 1996). Another form of name-date is shown below in Materials and Methods. For each reference, the complete citation must be given in the Literature Cited (Reference) section, discussed later. Papers with three or more authors are given an abbreviated format in the text: *et al*. means "and others", and is italicized to indicate it is a Latin phrase.

Avoid using direct quotes from your references, which are quite out of place in scientific writing. A citation is not an excuse to let another author speak for you. Instead, you should state in your own words what you have learned from your reading, while crediting the ideas and facts by use of citations. You can learn how to do this by reading the literature. Also, avoid using footnotes and endnotes. These are customary in the humanities literature, but are not used in scientific papers.

Materials and Methods

Here you describe how you did your experiments and analyzed your results. This is the easiest section to write, and is generally done first. You need not describe every detail if you used a method that was published elsewhere; you cite your source. For instance, "Nuclei in fixed hyphae were stained with the DNA-specific stain, mithramycin, following the method of Heath (1980)." Remember to have full details of where to find Heath (1980) in your reference list.

Try to get a good balance between detail and citation. Even if everything you do has been done exactly like the cited method, it helps to give a short description. This makes your paper easier to read, which you will remember is the most important rule of writing. So, for example, even if you followed Heath's (1980) method exactly you might say, "Briefly, fixed hyphae were stained for 5 min in 100μg/ml mithramycin (a gift of Pfizer, Pointe Claire-Dorval, PQ) in PIPES buffer, rinsed in plain buffer and mounted in Citifluor (Marivac, Halifax, NS)." If your reader wants more information, it is in Heath's paper. You would need to describe any changes from your published "standard", and explain substantial ones. Note that the first time you mention a chemical or important piece of equipment you must give its source, which helps those repeating your work. In my example, mithramycin and Citifluor were mentioned for the first time, unlike PIPES.

If you have no reference to cite for details of your methods, you must state every essential step so that your reader could repeat your experiment. Give recipes for solutions, and when they were applied and for how long. Following a published example will help with style. Avoid shopping lists for standard glassware and equipment. Be sure to indicate aspects of your procedure that, if done otherwise, might well have caused the results to be different. These facts will be important in comparing your results to what others may have seen when using the same or similar procedures.

Generally, you will have to explain how your data were collected. How were your specimens grown and/or what growth phase were they in? If cell numbers were monitored, how was this done and at what intervals? If morphology was examined, what aspects were considered and how were they described or quantified? For experimental reports, quantification is a more rigorous form of reporting than description, but often they are combined. Avoid 'many', 'some', or 'a few' in favour of '>80%', 'half', or '<10%'. Finally, write this section in the third person, past tense, passive voice. Do not say, "I boiled three flasks." Do say, "Three flasks were boiled." Above all, do not write this like a cookbook. Do not say, "After 24 h, examine the tubes for growth." Do say, "After 24 h, tubes were examined for growth."

Results (or Observations in a descriptive paper)

Here you state and show what you saw or measured. Do not make conclusions or discuss the data. That comes in the next section. However, data are not presented "raw"; they are analyzed so that they are meaningful. For example, if you monitored growth rates by taking four cell samples every hour, then counting and averaging the numbers, the number of cells you found in the original samples is not presented. Most important here are the final values, expressed as the average number of cells/ml, plus or minus a measure

of variation like the standard deviation. You must also state what measure of variability you used, and the statistical analysis of its significance (usually with a reference).

Photographs: Obviously these are a kind of raw data, but they must be either typical or representative (or occasionally exceptional – say which!), depending on the point you are trying to make. Generally, your data should be given as tables and figures (graphs and photos), each with a number and a title. Data that can be described in a sentence or two can be written out. Give each piece of data only once, not, for example, in a table and a graph, nor in a figure and the text. The text in the Results section should act as a tour guide, leading your reader from item to item (every figure or graph must be referred to, and in order), and drawing attention to the highlights, especially to those that will be important in making conclusions. What, if anything, all this means is given in the discussion.

Results are written in present or past tense. The present tense is more appropriate when describing results that you think represent absolute values. (The size of human red blood cells is about 7 μm, and you would expect any other researcher to find the same number.) The past tense is more appropriate when describing unique aspects of your results, such as a percent increase in reaction rate at an elevated temperature. It is possible, after all, that if someone repeats your work they may not find quite that exact percent increase, though of course you do expect them to find enough of an increase to agree with you that temperature has a stimulatory effect.

Discussion

This section has two purposes: to draw conclusions from your results and to compare your results with 1) what others have seen, or 2) what might have been expected in light of theory or hypothesis. It is impossible to fully interpret your own data without referring to related work. If you are writing a paper describing the differences between certain cells in two tissues, as well as the differences in your own micrographs, you must refer to what others have reported in that or other species. If nobody has looked at these particular cells before, still there is work on what some other cells look like, and so you should be comparing your cells to those. Where your results are different from what is expected, you should be proposing possible explanations. This, of course, might well involve you even more deeply in the literature, as you research the different functions of various organs or in the metabolism of separate species. Limit yourself to the comparisons between your work and the literature; a discussion is not a literature review.

Of all the sections, the discussion offers you the greatest opportunity for creativity. Use it, but do so wisely - remember, scientists are supposed to be constrained within the facts and laws of nature.

Literature Cited (References)

Often, shortcomings in a paper can be traced to inadequate amount or quality of reading. It is distressing to read a 15-page report and see that only two sources are referred to over

and over again. Your ideas must be supported adequately by reading from a variety of authoritative sources. For details on how to find these sources, see the article on effective library searches.

Wherever possible, use original research literature, articles or books in which ideas and data are presented for their first time. If you are reporting on experiments on the effect of light intensity on photosynthesis and are stressing in your discussion the similarity (or difference) of your results to those expected, you should cite the original articles from which those data come. Such articles (written, incidentally, in exactly the format you are now reading about) are found in journals with names like "Plant Physiology" or "Proceedings of the National Academy of Sciences", but not in "The World Book Encyclopedia" or in your first-year textbook.

Another kind of reference is a review article, either in certain books (e.g. "Annual Reviews of ..." or "Current Progress in ...", etc.), or sometimes in journals which also have original research results. Review articles analyze current knowledge on a certain topic. These papers are invaluable for the new ideas authors often propose, as well as for their extensive reference lists. Monographs are books devoted to a single subject and are like long review articles, and they should be used in the same way. Of a distinctly lower order of value are textbooks, except for texts in advanced courses, which may actually be monographs.

Occasionally, you will not be able to get a reference that you have seen mentioned in another source. Perhaps it is in an obscure journal, in a thesis, or it is in another language. In such a case, it is permissible to use the form: "Smith (1995) as cited in Jones et al (1996)", giving only Jones et al in the reference list. In this way, it is clear that you read Jones' paper and not Smith's, and tells your reader where to hunt for the Jones citation.

In writing this section, use only those sources to which you have already referred in your report. Above all, don't use this as a place to mention papers that you have not cited but only read along the way. List each reference alphabetically by first author, and use the "hanging indentation" form of indentation (shown below) to make it easy for your reader. A standard form is shown below.

For a journal article,

Hunsley, D. and J. H. Burnett. 1970. The ultrastructural architecture of the walls of some hyphal fungi. Journal of General Microbiology, 62: 203-218.

Osmani, A. H., S. A. Osmani, and N. R. Morris. 1990. The molecular cloning and identification of a gene product specifically required for nuclear movement in *Aspergillus nidulans*. J. Cell Biol. 111: 543-551. [This would have been Osmani *et al.* (1990) in the text]

For a book,

Alexopoulos, C. J. 1962. *Introductory Mycology*. 2nd. Ed. John Wiley and Sons, Inc. New York.

For a chapter in an edited book,

Grove, S. N. 1978. The cytology of hyphal tip growth. In, *The Filamentous Fungi*. Vol. 3. Edited by J. E. Smith and D. R. Berry. John Wiley and Sons. New York. pp. 28--50.

For an electronic (web) publication, give the author(s), year, title, e-journal (if appropriate) and URL

About Abbreviations

One word journal titles are never abbreviated. Common words like Biology (Biol.) have standard abbreviations. You can check these in a style manual or in an issue of Can. J. Bot. (Canadian Journal of Botany) or other appropriate journal. When in doubt, write the title out in full. Some journals have specific formats, but for Biol 342 use the formats given here.