How to Write a PhD Thesis

Getting Started

When you are about to begin, writing a thesis seems a long, difficult task. That is because it is a long, difficult task. Fortunately, it will seem less daunting once you have a couple of chapters done. Towards the end, you will even find yourself enjoying it---an enjoyment based on satisfaction in the achievement, pleasure in the improvement in your technical writing, and of course the approaching end. Like many tasks, thesis writing usually seems worst before you begin, so let us look at how you should make a start.

An outline

First make up a thesis outline: several pages containing chapter headings, sub-headings, some figure titles (to indicate which results go where) and perhaps some other notes and comments. There is a section on chapter order and thesis structure at the end of this text. Once you have a list of chapters and, under each chapter heading, a reasonably complete list of things to be reported or explained, you have struck a great blow against writer's block. When you sit down to type, your aim is no longer a thesis---a daunting goal---but something simpler. Your new aim is just to write a paragraph or section about one of your subheadings. It helps to start with an easy one: this gets you into the habit of writing and gives you self-confidence. In an experimental thesis, the Materials and Methods chapter is often the easiest to write – just write down what you did; carefully, formally and in a logical order.

How do you make an outline of a chapter? For most of them, you might try the method that I use for writing papers, and which I learned from my thesis adviser (Stjepan Marcelja): Assemble all the figures that you will use in it and put them in the order that you would use if you were going to explain to someone what they all meant. You might as well rehearse explaining it to someone else---after all you will probably give several talks based on your thesis work. Once you have found the most logical order, note down the key words of your explanation. These key words provide a skeleton for much of your chapter outline.

Once you have an outline, discuss it with your adviser. This step is important: s/he will have useful suggestions, but it also serves notice that s/he can expect a steady flow of chapter drafts that will make high priority demands on his/her time. Once you and your adviser have agreed on a logical structure, s/he will need a copy of this outline for reference when reading the chapters which you will probably present out of order. If you have a co-adviser, discuss the outline with him/her as well, and present all chapters to both advisers for comments.

Organisation

It is encouraging and helpful to start a filing system. Open a word-processor file for each chapter *and one for the references.* You can put notes in these files, as well as text. While doing something for Chapter n, you will think "Oh I must refer back to/discuss this in Chapter m" and so you put a note to do so in the file for Chapter m. Or you may think of something interesting or relevant for that chapter. When you come to work on Chapter m, the more such notes you have accumulated, the easier it will be to write.

***Make a back-up of these files and do so every day at least* (depending on the reliability of your computer and the age of your disk drive). Do not keep back-up close to the computer in case the hypothetical thief who fancies your computer decides that s/he could use some disks or membory as well.**

A simple way of making a remote back-up is to send it as an email attachment to a consenting email correspondent, preferably one in a different location. You could also send it to yourself. In either case, be careful to dispose of superseded versions so that you don't waste disk space, especially if you have bitmap images or other large files.

You should also have a physical filing system: a collection of folders with chapter numbers on them. This will make you feel good about getting started and also help clean up your desk. Your files will contain not just the plots of results and pages of calculations, but all sorts of old notes, references, calibration curves, suppliers' addresses, specifications, speculations, letters from colleagues etc., which will suddenly strike you as relevant to one chapter or other. Stick them in that folder. Then put all the folders in a box or a filing cabinet. As you write bits and pieces of text, place the hard copy, the figures etc in these folders as well. Touch them and feel their thickness from time to time – ah, the thesis is taking shape.

If any of your data exist only on paper, copy them and keep the copy in a different location. Consider making a copy of your lab book. This has

another purpose beyond security: usually the lab book stays in the lab, but you may want a copy for your own future use. Further, scientific ethics require you to keep lab books and original data for at least ten years, and a copy is more likely to be found if two copies exist.

If you haven't already done so, you should archive your electronic data, in an appropriate format. Spreadsheet and word processor files are not suitable for long term storage. Archiving data by Joseph Slater is a good guide.

While you are getting organised, you should deal with any university paperwork. Examiners have to be nominated and they have to agree to serve. Various forms are required by your department and by the university administration. Make sure that the rate limiting step is your production of the thesis, and not some minor bureaucratic problem.

A note about word processors

One of the big FAQs for scientists: is there a word processor, ideally one compatible with MS Word, but which allows you to type mathematical symbols and equations conveniently? One solution is LaTeX, which is powerful, elegant, reliable, fast and *free* from http://www.latex-project.org/ or http://www.miktex.org/. The standard equation editor for MS Word is point and click, so extremely slow and awkward. In many versions, Word's equation editor can be reached via hotkey Alt-equals, and takes pseudo latex typed input (eg X_1 converts to X subscript 1) upon the next space or operator. It uses some different formats - eg () rather than the {} of latex to group things and interprets divisions rather than having to use \frac. Here's a link: http://blogs.msdn.com/b/murrays/archive/2008/02/17/hidden-math-features-in-word-2007.aspx
It has been useful to know these as it seems biologists and latex don't mix!

A timetable

I strongly recommend sitting down with the adviser and making up a timetable for writing it: a list of dates for when you will give the first and second drafts of each chapter to your adviser(s). This structures your time and provides intermediate targets. If you merely aim "to have the whole thing done by [some distant date]", you can deceive yourself and procrastinate more easily. If you have told your adviser that you will deliver a first draft of chapter 3 on Wednesday, it focuses your attention.

You may want to make your timetable into a chart with items that you can check off as you have finished them. This is particularly useful towards the

end of the thesis when you find there will be quite a few loose ends here and there.

Iterative solution

Whenever you sit down to write, it is very important to write *something.* So write something, even if it is just a set of notes or a few paragraphs of text that you would never show to anyone else. It would be nice if clear, precise prose leapt easily from the keyboard, but it usually does not. Most of us find it easier, however, to improve something that is already written than to produce text from nothing. So put down a draft (as rough as you like) for your own purposes, then clean it up for your adviser to read. Word-processors are wonderful in this regard: in the first draft you do not have to start at the beginning, you can leave gaps, you can put in little notes to yourself, and then you can clean it all up later.

Your adviser will expect to read each chapter in draft form. S/he will then return it to you with suggestions and comments. *Do not be upset if a chapter---especially the first one you write--- returns covered in red ink (or its electronic equivalent).* Your adviser will want your thesis to be as good as possible, because his/her reputation as well as yours is affected. Scientific writing is a difficult art, and it takes a while to learn. As a consequence, there will be many ways in which your first draft can be improved. So take a positive attitude to all the scribbles with which your adviser decorates your text: each comment tells you a way in which you can make your thesis better.

As you write your thesis, your scientific writing is almost certain to improve. Even for native speakers of English who write very well in other styles, one notices an enormous improvement in the first drafts from the first to the last chapter written. The process of writing the thesis is like a course in scientific writing, and in that sense each chapter is like an assignment in which you are taught, but not assessed. Remember, only the final draft is assessed: the more comments your adviser adds to first or second draft, the better.

Before you submit a draft to your adviser, run a spell check so that s/he does not waste time on those. If you have any characteristic grammatical failings, check for them.

What is a thesis? For whom is it written? How should it be written?

Your thesis is a research report. The report concerns a problem or series of problems in your area of research and it should describe what was known about it previously, what you did towards solving it, what you think your results mean, and where or how further progress in the field can be made. Do not carry over your ideas from undergraduate assessment: a thesis is not an answer to an assignment question. One important difference is this: the reader of an assignment is usually the one who has set it. S/he already knows the answer (or one of the answers), not to mention the background, the literature, the assumptions and theories and the strengths and weaknesses of them. The readers of a thesis do not know what the "answer" is. If the thesis is for a PhD, the university requires that it make an original contribution to human knowledge: your research must discover something hitherto unknown.

Obviously your examiners will read the thesis. They will be experts in the general field of your thesis but, on the exact topic of your thesis, you are the world expert. Keep this in mind: you should write to make the topic clear to a reader who has not spent most of the last three years thinking about it.

Your thesis will also be used as a scientific report and consulted by future workers in your laboratory who will want to know, in detail, what you did. Theses are occasionally consulted by people from other institutions, and the library sends microfilm versions if requested (yes, still). More commonly theses are now stored in an entirely digital form. These may be stored as .pdf files on a server at your university. The advantage is that your thesis can be consulted much more easily by researchers around the world. (See e.g. Australian digital thesis project for the digital availability of research theses.) Write with these possibilities in mind.

It is often helpful to have someone other than your adviser(s) read some sections of the thesis, particularly the introduction and conclusion chapters. It may also be appropriate to ask other members of staff to read some sections of the thesis which they may find relevant or of interest, as they may be able to make valuable contributions. In either case, only give them revised versions, so that they do not waste time correcting your grammar, spelling, poor construction or presentation.

How much detail?

The short answer is: rather more than for a scientific paper. Once your thesis has been assessed and your friends have read the first three pages, the only further readers are likely to be people who are seriously doing

research in just that area. For example, a future research student might be pursuing the same research and be interested to find out exactly what you did. ("Why doesn't the widget that Bloggs built for her project work any more? Where's the circuit diagram? I'll look up her thesis." "Blow's subroutine doesn't converge in my parameter space! I'll have to look up his thesis." "How did that group in Sydney manage to get that technique to work? I'll order a microfilm of that thesis they cited in their paper.") For important parts of apparatus, you should include workshop drawings, circuit diagrams and computer programs, usually as appendices. (By the way, the intelligible annotation of programs is about as frequent as porcine aviation, but it is far more desirable. You wrote that line of code for a reason: at the end of the line explain what the reason is.) You have probably read the theses of previous students in the lab where you are now working, so you probably know the advantages of a clearly explained, explicit thesis and/or the disadvantages of a vague one.

Make it clear what is yours

If you use a result, observation or generalisation that is not your own, you must usually state where in the scientific literature that result is reported. The only exceptions are cases where every researcher in the field already knows it: dynamics equations need not be followed by a citation of Newton, circuit analysis does not need a reference to Kirchoff. The importance of this practice in science is that it allows the reader to verify your starting position. Physics in particular is said to be a vertical science: results are built upon results which in turn are built upon results etc. Good referencing allows us to check the foundations of your additions to the structure of knowledge in the discipline, or at least to trace them back to a level which we judge to be reliable. Good referencing also tells the reader which parts of the thesis are descriptions of previous knowledge and which parts are your additions to that knowledge. In a thesis, written for the general reader who has little familiarity with the literature of the field, this should be especially clear. It may seem tempting to leave out a reference in the hope that a reader will think that a nice idea or an nice bit of analysis is yours. I advise against this gamble. The reader will probably think: "What a nice idea---I wonder if it's original?". The reader can probably find out via the net or the library.

If you are writing in the passive voice, you must be more careful about attribution than if you are writing in the active voice. "The sample was prepared by heating yttrium..." does not make it clear whether you did this or whether Acme Yttrium did it. "I prepared the sample..." is clear.

Style

The text must be clear. Good grammar and thoughtful writing will make the thesis easier to read. Scientific writing has to be a little formal---more formal than this text. Native English speakers should remember that scientific English is an international language. Slang and informal writing will be harder for a non-native speaker to understand.

Short, simple phrases and words are often better than long ones. Some politicians use "at this point in time" instead of "now" precisely because it takes longer to convey the same meaning. They do not care about elegance or efficient communication. You should. On the other hand, there will be times when you need a complicated sentence because the idea is complicated. If your primary statement requires several qualifications, each of these may need a subordinate clause: "When [qualification], and where [proviso], and if [condition] then [statement]". Some lengthy technical words will also be necessary in many theses, particularly in fields like biochemistry. Do not sacrifice accuracy for the sake of brevity. "Black is white" is simple and catchy. An advertising copy writer would love it. "Objects of very different albedo may be illuminated differently so as to produce similar reflected spectra" is longer and uses less common words, but, compared to the former example, it has the advantage of being true. The longer example would be fine in a physics thesis because English speaking physicists will not have trouble with the words. (A physicist who did not know all of those words would probably be glad to remedy the lacuna either from the context or by consulting a dictionary.)

Sometimes it is easier to present information and arguments as a series of numbered points, rather than as one or more long and awkward paragraphs. A list of points is usually easier to write. You should be careful not to use this presentation too much: your thesis must be a connected, convincing argument, not just a list of facts and observations.

One important stylistic choice is between the active voice and passive voice. The active voice ("I measured the frequency...") is simpler, and it makes clear what you did and what was done by others. The passive voice ("The frequency was measured...") makes it easier to write ungrammatical or awkward sentences. If you use the passive voice, be especially wary of dangling participles. For example, the sentence "After considering all of these possible materials, plutonium was selected" implicitly attributes consciousness to plutonium. This choice is a question of taste: I prefer the active because it is clearer, more logical and makes attribution simple. The only arguments I have ever heard for avoiding the active voice in a thesis

are (i) many theses are written in the passive voice, and (ii) some very polite people find the use of "I" immodest. Use the first person singular, not plural, when reporting work that you did yourself: the editorial 'we' may suggest that you had help beyond that listed in your acknowledgments, or it may suggest that you are trying to share any blame. On the other hand, retain plural verbs for "data": "data" is the plural of "datum", and lots of scientists like to preserve the distinction. Just say to yourself "one datum is ..", "these data are.." several times. An excellent and widely used reference for English grammar and style is *A Dictionary of Modern English Usage* by H.W. Fowler.

Presentation

There is no need for a thesis to be a masterpiece of desk-top publishing. Your time can be more productively spent improving the content than the appearance.

In many cases, a reasonably neat diagram can be drawn by hand faster than with a graphics package, and you can scan it if you want an electronic version. Either is usually satisfactory. A one bit (i.e. black and white), moderate resolution scan of a hand-drawn sketch will be bigger than a line drawing generated on a graphics package, but not huge. While talking about the size of files, we should mention that photographs look pretty but take up a lot of memory. There's another important difference, too. The photographer thought about the camera angle and the focus etc. The person who drew the schematic diagram thought about what components ought to be depicted and the way in which the components of the system interacted with each other. So the numerically small information content of the line drawing may be much more useful information than that in a photograph.

Another note about figures and photographs. In the digital version of your thesis, do not save ordinary photographs or other illustrations as bitmaps, because these take up a lot of memory and are therefore very slow to transfer. Nearly all graphics packages allow you to save in compressed format as .jpg (for photos) or .gif (for diagrams) files. Further, you can save space/speed things up by reducing the number of colours. In vector graphics (as used for drawings), compression is usually unnecessary.

In general, students spend too much time on diagrams---time that could have been spent on examining the arguments, making the explanations clearer, thinking more about the significance and checking for errors in the algebra. The reason, of course, is that drawing is easier than thinking.

I do not think that there is a strong correlation (either way) between length and quality. There is no need to leave big gaps to make the thesis thicker. Readers will not appreciate large amounts of vague or unnecessary text.

Approaching the end

A deadline is very useful in some ways. You must hand in the thesis, even if you think that you need one more draft of that chapter, or someone else's comments on this section, or some other refinement. If you do not have a deadline, or if you are thinking about postponing it, please take note of this: *A thesis is a very large work. It cannot be made perfect in a finite time*. There will inevitably be things in it that you could have done better. There will be inevitably be some typos. Indeed, by some law related to Murphy's, you will discover one when you first flip open the bound copy. No matter how much you reflect and how many times you proof read it, there will be some things that could be improved. There is no point hoping that the examiners will not notice: many examiners feel obliged to find some examples of improvements (if not outright errors) just to show how thoroughly they have read it. So set yourself a deadline and stick to it. Make it as good as you can in that time, and then hand it in! (In retrospect, there was an advantage in writing a thesis in the days before word processors, spelling checkers and typing programs. Students often paid a typist to produce the final draft and could only afford to do that once.)

How many copies?

Talk to your adviser about this. As well as those for the examiners, the university libraries and yourself, you should make some distribution copies. These copies should be sent to other researchers who are working in your field so that:

- **they can discover what marvellous work you have been doing before it appears in journals;**
- **they can look up the fine details of methods and results that will or have been published more briefly elsewhere;**
- **they can realise what an excellent researcher you are. This realisation could be useful if a post- doctoral position were available in their labs. soon after your submission, or if they were reviewers of your research/post-doctoral proposal. Even having your name in their bookcases might be an advantage.**

Whatever the University's policy on single or double-sided copies, the distribution copies could be double-sided paper, or digital, so that forests and postage accounts are not excessively depleted by the exercise. Your

adviser could help you to make up a list of interested and/or potentially useful people for such a mailing list. Your adviser might also help by funding the copies and postage if they are not covered by your scholarship. A CD with your thesis will be cheaper than a paper copy. You don't have to burn them all yourself: companies make multiple copies for several dollars a copy.

The following comment comes from Marilyn Ball of the Australian National University in Canberra: "When I finished writing my thesis, a postdoc wisely told me to give a copy to my parents. I would never have thought of doing that as I just couldn't imagine what they would do with it. I'm very glad to have taken that advice as my parents really appreciated receiving a copy and proudly displayed it for years. (My mother never finished high school and my father worked with trucks - he fixed 'em, built 'em, drove 'em, sold 'em and junked 'em. Nevertheless, they enjoyed having a copy of my thesis.)"

Personal

In the ideal situation, you will be able to spend a large part---perhaps a majority---of your time writing your thesis. This may be bad for your physical and mental health.

Typing

Set up your chair and computer properly. The Health Service, professional keyboard users or perhaps even the school safety officer will be able to supply charts showing recommended relative heights, healthy postures and also exercises that you should do if you spend a lot of time at the keyboard. These last are worthwhile insurance: you do not want the extra hassle of back or neck pain. Try to intersperse long sessions of typing with other tasks, such as reading, drawing, calculating, thinking or doing research.

If you do not touch type, you should learn to do so for the sake of your neck as well as for productivity. There are several good software packages that teach touch typing interactively. If you use one for say 30 minutes a day for a couple of weeks, you will be able to touch type. By the time you finish the thesis, you will be able to touch type quickly and accurately and your six hour investment will have paid for itself. Be careful not to use the typing exercises as a displacement activity.

Exercise

Do not give up exercise for the interim. Lack of exercise makes you feel bad, and you do not need anything else making you feel bad

while writing a thesis. 30-60 minutes of exercise per day is probably not time lost from your thesis: I find that if I do not get regular exercise, I sleep less soundly and longer. How about walking to work and home again? (Walk part of the way if your home is distant.) Many people opine that a walk helps them think, or clears the head. You may find that an occasional stroll improves your productivity.

Food

Do not forget to eat, and make an effort to eat healthy food. You should not lose fitness or risk illness at this critical time. Exercise is good for keeping you appetite at a healthy level. I know that you have little time for cooking, but keep a supply of fresh fruit, vegetables and bread. It takes less time to make a sandwich than to go to the local fast food outlet, and you will feel better afterwards.

Drugs

Thesis writers have a long tradition of using coffee as a stimulant and alcohol or marijuana as relaxants. (Use of alcohol and coffee is legal, use of marijuana is not.) Used in moderation, they do not seem to have ill effects on the quality of thesis produced. Excesses, however, are obviously counter-productive: several espressi and you will be buzzing too much to sit down and work; several drinks at night will slow you down next day.

Others

Other people will be sympathetic, but do not take them for granted. Spouses, lovers, family and friends should not be undervalued. Spend some time with them and, when you do, have a good time. Do not spend your time together complaining about your thesis: they already resent the thesis because it is keeping you away from them. If you can find another student writing a thesis, then you may find it therapeutic to complain to each other about advisers and difficulties. S/he need not be in the same discipline as you are.

Coda

Keep going---you're nearly there! Most PhDs will admit that there were times when we thought about reasons for not finishing. But it would be crazy to give up at the writing stage, after years of work on the research, and it would be something to regret for a long time.

Writing a thesis is tough work. One anonymous post doctoral researcher told me: "You should tell everyone that it's going to be unpleasant, that it will mess up their lives, that they will have to give up their friends and their social lives for a while. It's a tough period for almost every student." She's right: it is certainly hard work, it will probably be stressful and you will

have to adapt your rhythm to it. It is also an important rite of passage and the satisfaction you will feel afterwards is wonderful. On behalf of scholars everywhere, I wish you good luck!

A suggested thesis structure

The list of contents and chapter headings below is appropriate for some theses. In some cases, one or two of them may be irrelevant. Results and Discussion are usually combined in several chapters of a thesis. Think about the plan of chapters and decide what is best to report your work. Then make a list, in point form, of what will go in each chapter. Try to make this rather detailed, so that you end up with a list of points that corresponds to subsections or even to the paragraphs of your thesis. At this stage, think hard about the logic of the presentation: within chapters, it is often possible to present the ideas in different order, and not all arrangements will be equally easy to follow. If you make a plan of each chapter and section before you sit down to write, the result will probably be clearer and easier to read. It will also be easier to write.

Copyright waiver

> **Your institution may have a form for this (UNSW does). In any case, this standard page gives the university library the right to publish the work, possibly by microfilm or other medium. (At UNSW, the Postgraduate Student Office will give you a thesis pack with various guide-lines and rules about thesis format. Make sure that you consult that for its formal requirements, as well as this rather informal guide.)**

Declaration

> **Check the wording required by your institution, and whether there is a standard form. Many universities require something like: "I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text. (signature/name/date)"**

Title page

> **This may vary among institutions, but as an example: Title/author/"A thesis submitted for the degree of Doctor of Philosophy in the Faculty of Science/The University of New South Wales"/date.**

Abstract

Of all your thesis, this part will be the most widely published and most read because it will be published in Dissertation Abstracts International. It is best written towards the end, but not at the very last minute because you will probably need several drafts. It should be a distillation of the thesis: a concise description of the problem(s) addressed, your method of solving it/them, your results and conclusions. An abstract must be self-contained. Usually they do not contain references. When a reference is necessary, its details should be included in the text of the abstract. Check the word limit. Remember: even though it appears at the beginning, an abstract is *not* an introduction. It is a résumé of your thesis.

Acknowledgments

Most thesis authors put in a page of thanks to those who have helped them in matters scientific, and also indirectly by providing such essentials as food, education, genes, money, help, advice, friendship etc. *If any of your work is collaborative, you should make it quite clear who did which sections.*

Table of contents

The introduction starts on page 1, the earlier pages should have roman numerals. It helps to have the subheadings of each chapter, as well as the chapter titles. Remember that the thesis may be used as a reference in the lab, so it helps to be able to find things easily.

Introduction

What is the topic and why is it important? State the problem(s) as simply as you can. Remember that you have been working on this project for a few years, so you will be very close to it. Try to step back mentally and take a broader view of the problem. How does it fit into the broader world of your discipline?

Especially in the introduction, do not overestimate the reader's familiarity with your topic. You are writing for researchers in the general area, but not all of them need be specialists in your particular topic. It may help to imagine such a person---think of some researcher whom you might have met at a conference for your subject, but who was working in a different area. S/he is intelligent, has the same general background, but knows little of the literature or tricks that apply to your particular topic.

The introduction should be interesting. If you bore the reader here, then you are unlikely to revive his/her interest in the materials and methods section. For the first paragraph or two, tradition permits prose that is less dry than the scientific norm. If want to wax lyrical

about your topic, here is the place to do it. Try to make the reader want to read the heavy bundle that has arrived uninvited on his/her desk. Go to the library and read several thesis introductions. Did any make you want to read on? Which ones were boring?

This section might go through several drafts to make it read well and logically, while keeping it short. For this section, I think that it is a good idea to ask someone who is not a specialist to read it and to comment. Is it an adequate introduction? Is it easy to follow? There is an argument for writing this section---or least making a major revision of it---towards the end of the thesis writing. Your introduction should tell where the thesis is going, and this may become clearer during the writing.

Literature review

Where did the problem come from? What is already known about this problem? What other methods have been tried to solve it?

Ideally, you will already have much of the hard work done, if you have been keeping up with the literature as you vowed to do three years ago, and if you have made notes about important papers over the years. If you have summarised those papers, then you have some good starting points for the review.

If you didn't keep your literature notes up to date, you can still do something useful: pass on the following advice to any beginning PhD students in your lab and tell them how useful this would have been to you. When you start reading about a topic, you should open a spread sheet file, or at least a word processor file, for your literature review. Of course you write down the title, authors, year, volume and pages. But you also write a summary (anything from a couple of sentences to a couple of pages, depending on the relevance). In other columns of the spread sheet, you can add key words (your own and theirs) and comments about its importance, relevance to you and its quality.

How many papers? How relevant do they have to be before you include them? Well, that is a matter of judgement. On the order of a hundred is reasonable, but it will depend on the field. You are the world expert on the (narrow) topic of your thesis: you must demonstrate this.

A political point: make sure that you do not omit relevant papers by researchers who are like to be your examiners, or by potential

employers to whom you might be sending the thesis in the next year or two.

Middle chapters

In some theses, the middle chapters are the journal articles of which the student was major author. There are several disadvantages to this format.

One is that a thesis is both allowed and expected to have more detail than a journal article. For journal articles, one usually has to reduce the number of figures. In many cases, all of the interesting and relevant data can go in the thesis, and not just those which appeared in the journal. The degree of experimental detail is usually greater in a thesis. Relatively often a researcher requests a thesis in order to obtain more detail about how a study was performed.

Another disadvantage is that your journal articles may have some common material in the introduction and the "Materials and Methods" sections.

The exact structure in the middle chapters will vary among theses. In some theses, it is necessary to establish some theory, to describe the experimental techniques, then to report what was done on several different problems or different stages of the problem, and then finally to present a model or a new theory based on the new work. For such a thesis, the chapter headings might be: Theory, Materials and Methods, {first problem}, {second problem}, {third problem}, {proposed theory/model} and then the conclusion chapter. For other theses, it might be appropriate to discuss different techniques in different chapters, rather than to have a single Materials and Methods chapter.

Here follow some comments on the elements Materials and Methods, Theory, Results and discussion which may or may not correspond to thesis chapters.

Materials and Methods

This varies enormously from thesis to thesis, and may be absent in theoretical theses. It should be possible for a competent researcher to reproduce exactly what you have done by following your description. There is a good chance that this test will be applied: sometime after you have left, another researcher will want to do a similar

experiment either with your gear, or on a new set-up in a foreign country. Please write for the benefit of that researcher.

In some theses, particularly multi-disciplinary or developmental ones, there may be more than one such chapter. In this case, the different disciplines should be indicated in the chapter titles.

Theory

When you are reporting theoretical work that is not original, you will usually need to include sufficient material to allow the reader to understand the arguments used and their physical bases. Sometimes you will be able to present the theory *ab initio*, but you should not reproduce two pages of algebra that the reader could find in a standard text. Do not include theory that you are not going to relate to the work you have done.

When writing this section, concentrate at least as much on the physical arguments as on the equations. What do the equations mean? What are the important cases?

When you are reporting your own theoretical work, you must include rather more detail, but you should consider moving lengthy derivations to appendices. Think too about the order and style of presentation: the order in which you did the work may not be the clearest presentation.

Suspense is not necessary in reporting science: you should tell the reader where you are going before you start.

Results and discussion

The results and discussion are very often combined in theses. This is sensible because of the length of a thesis: you may have several chapters of results and, if you wait till they are all presented before you begin discussion, the reader may have difficulty remembering what you are talking about. The division of Results and Discussion material into chapters is usually best done according to subject matter.

Make sure that you have described the conditions which obtained for each set of results. What was held constant? What were the other relevant parameters? Make sure too that you have used appropriate statistical analyses. Where applicable, show measurement errors and standard errors on the graphs. Use appropriate statistical tests.

Take care plotting graphs. The origin and intercepts are often important so, unless the ranges of your data make it impractical, the zeros of one or both scales should usually appear on the graph. You should show error bars on the data, unless the errors are very small. For single measurements, the bars should be your best estimate of the experimental errors in each coordinate. For multiple measurements these should include the standard error in the data. The errors in different data are often different, so, where this is the case, regressions and fits should be weighted (i.e. they should minimize the sum of squares of the differences weighted inversely as the size of the errors.) (A common failing in many simple software packages that draw graphs and do regressions is that they do not treat errors adequately. UNSW student Mike Johnston has written a plotting routine that plots data with error bars and performs weighted least square regressions. It is at http://www.phys.unsw.edu.au/3rdyearlab/graphing/graph.html). You can just 'paste' your data into the input and it generates a .ps file of the graph.

In most cases, your results need discussion. What do they mean? How do they fit into the existing body of knowledge? Are they consistent with current theories? Do they give new insights? Do they suggest new theories or mechanisms?

Try to distance yourself from your usual perspective and look at your work. Do not just ask yourself what it means in terms of the orthodoxy of your own research group, but also how other people in the field might see it. Does it have any implications that do not relate to the questions that you set out to answer?

Final chapter, references and appendices

Conclusions and suggestions for further work

Your abstract should include your conclusions in very brief form, because it must also include some other material. A summary of conclusions is usually longer than the final section of the abstract, and you have the space to be more explicit and more careful with qualifications. You might find it helpful to put your conclusions in point form.

It is often the case with scientific investigations that more questions than answers are produced. Does your work suggest any interesting further avenues? Are there ways in which your work could be

improved by future workers? What are the practical implications of your work?

This chapter should usually be reasonably short---a few pages perhaps. As with the introduction, I think that it is a good idea to ask someone who is not a specialist to read this section and to comment.

References (See also under literature review)

It is tempting to omit the titles of the articles cited, and the university allows this, but think of all the times when you have seen a reference in a paper and gone to look it up only to find that it was not helpful after all.

Should you reference web sites and, if so, how? If you cite a journal article or book, the reader can go to a library and check that the cited document and check whether or not it says what you say it did. A web site may disappear, and it may have been updated or changed completely. So references to the web are usually less satisfactory. Nevertheless, there are some very useful and authoritative sources. So*, if the rules of your institution permit it,* it may be appropriate to cite web sites. (Be cautious, and don't overuse such citations. In particular, don't use a web citation where you could reasonably use a "hard" citation. Remember that your examiners are likely to be older and more conservative.) You should give the URL and also the date you downloaded it. If there is a date on the site itself (last updated on .....) you should included that, too.

Appendices

If there is material that should be in the thesis but which would break up the flow or bore the reader unbearably, include it as an appendix. Some things which are typically included in appendices are: important and original computer programs, data files that are too large to be represented simply in the results chapters, pictures or diagrams of results which are not important enough to keep in the main text.
