How to write a thesis

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February 2010

Abstract

By applying a few general rules during the writing of a BSc, MSc or PhD thesis, the resulting document can become a pleasure to evaluate. The concomitant positive disposition of the referee, for whom a positive correlation between mood and grade has been determined, will then likely imply that a score worthy of the scientific achievement presented in the thesis will be awarded. In the interests of maintaining both parameters (mood and grade) at positive levels, a set of guidelines is given which, if followed assiduously, may result in a written document in which the words do not get in the way of the science.

Contents

1 Motivation

The purpose of your thesis is to describe a scientific advance. You are writing it to demonstrate to the reader what you have done in your research, why it is relevant, and what about it is new. You want the reader to understand what it is that you have been doing for the past three or four years.

A thesis is *not*, on the other hand, a Joycean compendium of literary challenges designed to befuddle the hapless reader with torrent of obfuscatory prose. Nor is it a platform to demonstrate the writer's skill in applying superficially impressive but ultimately frivolous pyrotechnical formatting in which the number of fonts exceeds the number of ideas. Nor should it aspire to be a Tolstoyan epic before which entire Siberian forests quake in terror at the thought of it being printed out.

Your thesis is a succinct, intelligible and complete description of your scientific work, designed for the technically versed reader. Not more, not less.

2 Structure

The fundamental problem in many theses is not mangled grammar or misplaced commas, but rather incomprehensible structure: of individual paragraphs, of sections, and of the document as a whole. Applying a logical structure to the work is often half the battle.

2.1 Overall

The purpose of your thesis is to describe technical and scientific developments. The overall structure should thus typically be as follows:

Introduction A brief summary of the contents of the thesis, including what was done and, in general terms, what was achieved. Two pages maximum.

Motivation Explanation of why you had to do what you did, including a synoptic survey of the state-of-the-art with extensive references. At the end of this section, you should summarize your most important results in one to two pages, including your best measurement result.

Theory Presentation (or derivation, if necessary) of the theoretical basis required for an understanding of your work. Do not begin with Newton's

laws or Maxwell's equations: imagine that the reader is a competent engineering professor, but not necessarily in your field of expertise. Do not bother to discuss any theory that you do not employ in later sections.

Approach Description of the approach you have taken to solve the scientific or technical problem which you were posed. Outline the design, the methodology and overall structure of your experimental approach.

Fabrication Outline of the technologies used to fabricate and assemble your structures, if applicable. Detailed processes belong in the appendix. If numerous types of structures were fabricated, or assembly technology is extensive, there may be more than one of these chapters.

Characterization Description of the means developed and employed to characterize the devices or systems that have been fabricated. If trivial, this section can be combined with the next.

Measurement results The heart of the thesis, comprising a presentation of the functioning system and thus the culmination of the work. Important is an analysis of the results as well as a comparison with the state of the art. The reader should understand in this section why you should be awarded a BSc/MSc/PhD degree.

Outlook A summary of the most important results, whereby a repeated emphasis of their relevance, importance and novelty cannot hurt. A brief precis of the envisaged future potential of the work is suitable here, but avoid addressing the Nobel Committee directly.

2.2 Sub-sections

A chapter covers one major topic in your thesis, such as *Fabrication* or *Characterization*. It should be divided into sub-sections which address a single aspect of the topic of the chapter; each subsection should be self-contained. If several related topics are considered in a subsection, you may consider sub-subsections.

A typical structure may then look like this:

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Chapter 5 - Characterization
   5.1 Measurement setup
      5.1.1 Optics
      5.1.2 Mechanics
      5.1.3 Electronics
   5.2 Power measurements
   5.3 Spectral measurements
      5.3.1 Grating spectrometer
      5.3.2 Fabry-Perot interferometer
      ...
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- Each chapter should begin with a short introduction including a motivation for the subject, i.e., why do we need to address this topic and how does it fit into the thesis as a whole? Thus subsection 5.3, for example, might begin as:

  > For their application in the spectroscopy system which is the subject of this thesis, the spectral properties of the laser diodes need to be accurately determined. We accomplish this using two techniques: the grating spectrometer yields an overview of the spectrum in a broad wavelength range, whereas the Fabry-Perot interferometer is used to examine the emission peak at high resolution.

- Each subsection should be structured logically. It should likewise have a short introductory paragraph, describe the experiment and approach, give the results and discuss their relevance (in that order). So subsection 5.2 might be structured as, for example:

  1. Introduction – power measurements are required to assure that at least 5 mW are emitted.
  2. Approach – an integrating sphere and commercial power meter for the near-IR were used.
  3. Results – PI curves at a range of temperatures were measured for five different laser diodes.
  4. Discussion – Diodes A–D have sufficient power, diode E shows a degradation at high temperature.
  5. Implications – Diode B will be used in the spectroscopy experiments due to its optimal power output.

- Dividing the sub-sub-subsections too finely (say, by going down to the level of 5.3.2.7.VI.§5) may be good for lawyers but is considered in bad taste for engineers.

2.3 Paragraphs

The fundamental unit of your text is the paragraph. Writing a good paragraph is the most important and the most tricky part of generating a readable text.

- Each paragraph contains *one idea*.
- If your paragraph has more than a half dozen sentences, you probably have more than one idea. Initiate paragraphic mitosis.
- When you start your paragraph, ask yourself: What do I want to say? Why should the reader care? How can I express this most clearly?
- Your paragraph needs a structure: the first sentence introduces your idea, the central ones express and develop it and the final one summarizes.

- Your paragraph has to have some connection with the one preceding it; if your next thought requires a conceptual leap in subject matter, then consider starting a new sub-subsection.

3 Words

English is not the native language for many of you. As a result, you have to pay particular attention to the words from which you assemble your text.

3.1 Passive vs. active

You should endeavor to use the active voice; it makes your text more dynamic than if you employ the passive voice. What is the difference? Compare the two sentences:

Active Technical writing has traditionally used the passive voice but the active voice is rapidly gaining in popularity.

Passive The passive voice has traditionally been used for technical writing but the popularity of the active voice is increasing.

- Use the active voice if possible. Thus

  > Figure 13 shows the laser spectrum at different temperatures and these measurements confirm mono-mode operation under a wide range of conditions.

  is to be preferred to

  > The laser spectrum at different temperatures is seen in Figure 13 and mono-mode operation under a wide range of conditions is thus confirmed.

- The active voice does not necessarily imply the use of personal pronouns (I, you, we, he, she, they); see the discussion of Section 3.4

- You can filter out passive sentences by looking for lavish use of the verb "to be"; if you are confronted with a plethora of is, was, were, has been, and so forth, you are probably excessively passivated.

- The one place where the passive voice is to be preferred is in the *Fabrication* or *Characterization* sections. If you are describing process steps or equipment setups, the passive voice is appropriate.

3.2 Tense

Technical writing also traditionally uses the past tense; the work you have done is in the past, so that, with exception of the *Outlook* section, it is generally best to stick to the past tense.

- Use the simple past:

  > We measured the output power using an integrating sphere and compared the data to measurements performed on commercial laser diodes.

- The present tense is not necessarily forbidden fruit, particularly in the *Theory* or *Measurement results* sections:

  > These results are astonishing since it has long been assumed that the acid from the tangerines would etch the laser facet.

- The future tense may be used the *Outlook* section:

  > The laser developed here will be of particular value for high-resolution spectroscopy of citrus fruits.

- Do not flop back and forth or mix-and-match excessively:

  > The measurement employs a high-resolution spectrometer whereby an avalanche photodiode was used to determine the output power, which we will use as a reference value in other experiments.

3.3 Vocabulary

English is a very rich language, with a frighteningly lavish vocabulary, including innumerable words which mean almost, but not quite, the same thing. The thesaurus can prevent incipient boredom by proposing a host of alternatives for a simple verb, like "to annoy", aptly demonstrated by a sign at the San Diego zoo which bade visitors: "Please do not annoy, torment, pester, plague, molest, worry, badger, harry, harass, heckle, persecute, irk, bullyrag, vex, disquiet, grate, beset, bother, tease, nettle, tantalize, or ruffle the animals". (Fromkin et al., 2007, p. 189)

Luckily the reader tends not to be bored either, howling with laughter imagining angry atoms since they have been "enraged" by photons. Alas, "excited" has a similar meaning, but then again, not exactly. Alternatively, you can be "fixated" on your work, your hobby or your girlfriend, but you "fix" chips to a substrate.

- By all means, use a thesaurus to expand your vocabulary, but look up the proposed alternatives in the dictionary to find their exact meaning.

- Ergo: never ever use a word unless you are sure exactly what it means.

- When in doubt, consult a dictionary.
- Even when not in doubt, consult a dictionary.
- Use the simplest word possible with the simplest sentence structure possible. Thus

  > An augmentation of ambient kinetic energy proved to be imminently responsible for a spectral diminution of the emission apex of the radiant source to an inappreciable magnitude

  can advantageously be replaced by

  > Laser emission degraded at higher temperatures.

3.4 Personal pronouns

Most science writing is, with a few notable exceptions, impersonal. Thus phrases such as

> I measured my laser using our infrared photodiode and you can see that the spectral peak we obtained is at 852 nm, as I have presented in the following figure.

are usually frowned upon, and are beneficially replaced by

> The peak of the laser emission, measured using an IR photodiode, was at 852 nm, as is seen in the following figure.

- Avoid the personal pronouns (I, you, we, he, she, they).
- Constructions such as "my lens" or "our laser" make a particularly puerile impression. Eschew these.
- Avoid mentioning authorities by name unless they are particularly authoritative. Thus

  > . . . as was already shown by Einstein in 1905.

  is acceptable, but

  > Using obscure code written by my roommate Ebenezer Scrooge, the pecuniary output functions were minimized.

  is not. Add a reference and relegate Scrooge to the Acknowledgements.
- There are two general exceptions: in the *Introduction* and *Conclusions*, the plural personal pronoun "we" is appropriate. Thus an introductory paragraph might begin as

> We present here a new type of semiconductor laser designed to function while dunked in tangerine marmalade. Our experiments have shown that this immersion does not significantly affect the operating characteristics. We propose a theoretical model which explains the measured orange-shift in spectral output under these operating conditions and discuss means for removing the caramel from the laser facet.

3.5 Clarity

A popular witticism laments that "Scientists attempt to express the maximum number of ideas using the minimum number of words. Poets do the opposite."

- You are writing an engineering thesis, not poetry.
- Phrases like

  > Semiconductor lasers have numerous important characteristics. These have to be measured accurately and with great care using sensitive and complicated equipment. Characterization is therefore of great value and of considerable importance as a part of the work performed, and accurate values of, for example, output power, form part of the catalogue of parameters which need to be unequivocally determined. The spectrum is also important. Such measurements should be performed at the outset of experimental work, and can be done if the mood of the researcher is not adversely affected by the stray magnetic fields perfusing the laboratory.

  are more practically replaced by

  > The PI curve and spectrum of the laser diode were measured.

- Be precise and concrete; write exactly what measurement you performed, how you interpreted the data and why this is relevant.
- Use simple, clear words.
- Write short sentences.
- Ask yourself if your mother would understand what you have just written.

3.6 Things to avoid

There are dozens of details in usage which may not be wrong but still irritating or awkward. The following are some which vex me in particular.

- Do not begin a sentence with "This is ..." . The word "this" is not a subject. Be specific, as in "This process step is ..." or "This result is ...".

- Avoid words like "obviously" or "clearly". If it's obvious, you don't have to write it.
- The phrase "in order to" can always be replaced by "to".
- "Respectively" does not mean "or". Instead, it is used in the sense of "The emission wavelengths at low and high temperatures were 851.3 and 852.4 nm, respectively." meaning the wavelength was 851.3 nm at low temperature and 852.4 nm at high temperature.
- You can easily do without phrases such as "The laser diodes were operated and characterized." or "The measurement setup was set up." Even the inattentive reader pretty much assumes you have done that.

4 Equations and figures

Most cross-references in your text will be to equations, figures and tables. These must be referred to properly.

- Figures and equations are numbered in ascending sequence. So 1,2,3,4,... not 1,7,14,5,....
- *All* figures and tables must be referenced in the text.
- References to equations, figures and tables should flow into the text, thus in the form "The spectrum showed a distinct second peak, as seen in Figure 13.53." and not "The spectrum showed a distinct second peak (Figure 13.53)".
- When writing "Figure xx", "Equation yy", and "Table zz", the words "Figure", "Equation", and "Table" are capitalized, but when used in phrases like "... as we saw in the previous equation...", they are not.

4.1 Equations

- Equations are part of the text. Therefore, we write

  While we can assert with reasonable confidence that

  $$1 + 1 = 2, \tag{1}$$

  we prefer to write this last expression more obtusely as (Siegfried, 1970)

  $$\ln e + \left(\sin^2 \xi + \cos^2 \xi\right) = \sum_{n=0}^{\infty} \frac{1}{2^n}. \tag{2}$$

- Equations may need punctuation. Notice that Equation 1 takes a comma and 2 has a period, since the latter is the end of the sentence.

- All variables (even those not in equations) must be defined. Even if it is obvious to you that S is entropy, for me it might mean the arc length of a conic section.
- Variables are in *italics* and units are not. So S may be entropy, but S implies the unit Siemens.

4.2 Figures

- Use figures extensively. A nine-paragraph description of five-etch-step, three-photolithography step, dual-sided wafer-bonded laser-diced fabrication process is best described with a set of cross-sectional sketches.
- All photos need a scale. Using references objects such as coins, pencil tips or dead flies is quaint but useless. Or do you know the diameter of a 7 renminbi coin? Please add a scale bar.
- All axes have to be labeled, with units.
- A profusion of bullets (stars, squares, filled circles, hatched pentagrams, etc.) on a graph rapidly develops into an astrological cloud of confusing symbols. If you have more than two or three curves, consider using more than one figure.
- Use lines which can be easily distinguished from each other: solid, dotted, dashed. Think in black-and-white; more than three grey tones rapidly become indistinguishable. If you have too much data, split the graphics into several figures.
- Captions should say something about the figure. Therefore, writing

  > The laser spectrum.

  is less useful than, for example,

  > The emission spectrum of laser diode B15, measured at room temperature at a drive current of 23 mA; the incipient side-lobes clearly show the onset of multi-mode emission.

- The indolent reader should in principle be able to glean the most important information in your chapter by perusing the figures and associated captions, not that any professors would ever do that.

5 References

A good thesis requires a solid set of references, indicating to the reader that you know the field, are acquainted with prior art and have adequately recognized work relevant to your research.

5.1 Required literature

- The *Background*, *State-of-the-art* and *Previous research* sections should be well referenced. This shows the reader you know the field.
- References are also required as support (particularly in the theory section) for brazen assertions such as

  > It is a widely accepted fact that Hans Zappe is of extraterrestrial origin (Zappe, 2010c).

- Generally accepted knowledge (Maxwell's equations, the general principles of laser operation, recipes for crème brûlé ...) needs not be referenced.
- In principle you can decide whether to use abbreviations in your literature lists or not, both for author given names (i.e., "M. Zappe" or "Max Zappe") and journal titles. However, I think (Zappe, 2010a) is more useful than (Zappe, 2010b); thus I propose *not* abbreviating journal titles. Whatever you do, please be consistent.

5.2 Citations

- The author-date system, which uses citations of the form (Zappe, 2010c), has become the publishing standard. Whereas some organizations, notably the IEEE, still use numbered references, the author date system yields a much more usable bibliography.

5.3 Sources

- Only use publicly-available sources, preferably those which appeared in peer-reviewed journals or high-profile conference proceedings.
- If you use unpublished information from an authority in a particular subject, then a reference like "Harry Potter, personal communication" is acceptable but of marginal utility.
- Putting web sites or Wikipedia into your bibliography is a guaranteed way to decrease your thesis grade by 0.3 points. Per occurence.

6 Varia

6.1 Resources

The world does not need another style manual and this isn't one. Although they can be voluminous and not necessarily a thrilling read, style books are a valuable resource and it would doubtlessly be of value to peruse one or two. Widely accepted (and recommended by, for example, the IEEE) is the *The Chicago Manual of Style* published by the University of Chicago Press. Use it to your advantage.

6.2 Footnotes

Use footnotes sparingly[1] and reserve them for truly parenthetical comments[2]. In 9^3 times out of 10^4, you can delete the footnote text without any loss of useful content.

6.3 Acronyms

Tame your use of acronyms. Whereas generally accepted acronyms should be defined and can then be used, avoid defining too many of your own which the reader then has to memorize. A sentence like

> The 3D TPM was fabricated by DRIE of PDMS on BK-7 with KOH post-processing using 3 PL steps and, due to enhanced NA, provided better DOF in TD-, SS- and FD-OCT systems as verified by improved SNR in the PC-processed GPIB output when viewed at VGA resolution by a LOL with limited ocular MTF.

is not particularly readable, even if all the acronyms are relatively standard.

6.4 Nerves

Spare yourself the nervous breakdown; write your thesis in LaTeX.

7 Acknowledgements

None of us sits monk-like in a cell and generates the material for a thesis through pure thought, divine inspiration or Red Bull-induced hallucinations.

- Be generous: thank all of those who have helped you in some way, even if just a little bit. Most science is a collective endeavor, and people are happy to have their contributions recognized.
- Use agreeable active phrases like "I am grateful to…", "I am thankful for…", or "It is a pleasure to thank…".
- It's always nice to specify what a person did for you:

  > I am grateful to Douglas Engelbart for having invented the computer mouse and to Prof. Zappe for keeping his hands off my optical table.

- I am grateful to Claudia Duppé for helping me to clarify my position on the active and passive voices.

[1] They distract the reader by interrupting the flow of the text.

[2] The fact is, the reader nearly always reads them, and is then frequently irritated by their lack of relevance.

[3] This value has not been verified experimentally.

[4] And never, ever use a footnote after a numeral or a mathematical expression; in the above sentence, the reader might well think I meant "243 times out of 10 000"

References

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