How to write a paper

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Abstract

Writing technical papers is an essential part of your engineering education, but the birth of a good scientific manuscript is often fraught with untold difficulties and sinister traps. To help guide the student through the dark sinuous passages which lead from a dazzling experimental result to a much-cited publication, we have assembled here a few practical methods, useful tools and gratuitous tips to help expedite this scientific literary odyssey.

Contents

1 Getting started

Obtaining a PhD without writing and publishing at least one paper is virtually impossible. It is thus inevitable that, sooner or later, your advisor will insist that your latest measurement of lasing in an edible gelatin is suitable for publication and that you should prepare a paper. The subsequent indigestion you sense is likely not due to the fact that you have just eaten your light source, but that you have only the vaguest idea of how to proceed. Let's go through a list of steps which will help you formulate your publication.

Define your topic Ask yourself: "What is my paper about?" Typically it is not as broad as your entire PhD thesis, but is one aspect of it. Determine *what* scientific or technical development (a measurement, a new device, a novel effect) you wish to publish, and that will be the topic of your paper. Avoid trying to pack too much into a single publication: if you have a broad variety of results, consider several separate publications.

Dream up a title Coming up with a title at the start may help you to focus on the topic of the manuscript and constantly remind you about the scientific message you are aiming to transmit. The title should accurately reflect the central thesis: thus "Lasing from an edible, optically active gelatinous medium" is to be preferred to "Novel uses for raspberry Jello".

Collect figures Once the topic of the paper is more-or-less clear, one way to help yourself in determining the structure and contents of your paper is to collect the figures you intend to include. Generate plots of the data from your experiments, diagrams of the experimental setup and photos of the samples. Spread them out on a table and see if they tell a story.

Make an outline Once you have a collection of your nicest figures, you know *what* you want to write about. Now make an outline of *how* you want to present it. Imagine you are describing your work to a technically literate person, but not necessarily someone intimately familiar with your work. Think about what background you would need to describe so that this person can understand your result: for example,

some theory, a description of fabrication processes or the experimental setup and an interpretation of your measurements. List these aspects in a logical sequence, and you have your outline; we will discuss some of the essential parts of such a sequence in Section 4.1. Now you are almost ready to write.

2 Journals

How and what you write will depend on the *type* of publication you are envisaging. You need to consider the type of publication carefully, since each requires fundamentally different kinds of writing.

2.1 Publication types

In general, your work will probably be published in one of three basic forms:

Journal paper A journal paper is the most suitable outlet for the results of a longer research program. Journal papers can be long (typical length limitations might be 12 pages), in which you can write an extensive description of your experimental work. Most PhD students aim for a journal paper toward the end of their projects. Journal papers can take a long time to appear: 6 to 12 months is common.

Letter A "letter" is a short paper, typically limited to three pages. Letters are suitable for exciting and time-critical results, which should appear quickly. In three pages, you have to describe your result in a very compact manner, so that letters are not suitable for providing an overview of a long research effort. Editors often decide that a letters submission is of high quality but not of sufficient urgency to merit rapid publication, and your submission may be redirected to a normal journal.

Conference proceedings Presentation of your work at a conference is an ideal way to rapidly disseminate the results of your research to a broad audience, with a rapid time-to-publication. Typically you have to write a short abstract (between 100 and 600 words) based on which your paper will be accepted or not. A longer (typically 2 – 4 pages, but in some cases [such as for SPIE] up to 12 pages) paper then appears in the conference proceedings volume, allowing you to describe your work in more detail. Since these proceedings are generally reviewed only cursorily or not at all, these are considered to be less "valuable" publications.

2.2 Picking a journal

Once you have decided on a journal paper, letter, or conference paper, you have to decide to *which* journal or conference you wish to submit your work.

Here you have to do some research: find copies of some of the journals which come into question and look at the kinds of papers published; examine the journal web sites and determine the scope; and find out who else has published there. The following considerations are important:

Scope What are the topics covered by the journal? Does your work fit? Work on edible lasers might be publishable in *IEEE Transactions on Quantum Electronics*[*] but most probably not in the *Journal of Food Science*.

Impact The impact factor of a publication is a measure for the average number of times articles in a particular journal are cited in a particular year. Impact factor has become a obsessively misused tool to estimate journal "quality" and a gold mine for research bureaucrats yearning for a single number with which they can pigeon-hole scientists. Do consider the reputation of a journal for your field and sub-discipline: you should publish in the best journal possible. But don't obsess about impact factor; a high-impact journal such as *Nature*, for example, only considers a relatively narrow scope of research and it is virtually impossible for engineering work to be published there.

Speed Time-to-publication varies strongly between journals. Long review times are a headache for editors as well as authors, but since everyone involved (authors, editors, reviewers) usually performs these functions as a volunteer, there is little one can do to expedite the publication process. Talk to your colleagues and try to determine a journal's reputation for speed; if you have a truly exciting result, consider a letters publication, as these are generally much faster than journals.

Open access? There is an increasing number of high-quality open access journals, many founded in response to the rapacious library subscription policies of the large scientific publishers. Even though your advisor will have to pay a few kilo-Euros to have the paper published, consider submitting there. The impact of many open access journals is greater than that of many traditional print journals.

2.3 Format

Now that you have picked a journal, you should navigate to its home page and look at the submission guidelines. These are important, since sending a paper with technical (as opposed to scientific) faults will result in an email stating "Navigate to our home page and look at the submission guidelines."

[*]It has been: (Hänsch et al., 1971).

- See if a formatting template is required. Many journals do typesetting themselves, so you can send the text and figures any way you like; in that case, don't waste your time with formatting.

  On the other hand, many conferences have strict template requirements for the submitted abstracts. Thus if the guidelines state:

  > Your submission must be written using a turquoise colored 13 point Plantagenet Cherokee font and centered in a heptagonal area positioned at the lower left of a sheet of Pantone 604 Swedish D4 paper.

  then you had better do so. Even if they sound silly or break all the rules of good aesthetic taste, follow the guidelines, or your submission will be rejected on technical grounds.

- Pay close attention to length requirements: most journals do have length limitations, or levy pecuniarily painful page charges for overlength papers. Letters papers are usually very strict, at typically three pages; anything longer is rejected without review. Conference abstracts often have a ironclad maximum word count; please note that reviewers are usually not amused if authors subsequently put 1 000 words of text in the figure captions, so don't try.

- Follow guidelines concerning the format of references and figures. Even for journals that typeset the final manuscript, it is expected that you provide references and citations in the proper format.

3 Tools

3.1 Background tools

A bit of preparatory research work can help ease the paper writing process, especially if this is your first paper.

- Read a few papers in the journal to which you are submitting to get a feeling for the style.

- Read *How to write a thesis*; many topics addressed there are relevant here, and indeed, sections 5 and 6 of the disquisition you are reading are lifted directly from that tract.

- Read how a journal editor with years of experience (Steve Senturia of MIT) sees the publication process and how one can avoid having one's paper axed (Senturia, 2003).

3.2 Software tools

You are not going to write your manuscript by scratching a goose quill on parchment, but your choice of word processing software can either instigate or obviate debilitating migraines. An admittedly personal view:

- Use LaTeX.
- Find a LaTeX style for the journal to which you are submitting. Google it: almost everything exists.
- Remove *all* the %`comments` from the LaTeXfile, except perhaps a few %– – ––– to separate sections; comments are advantageously used in the editorial process.
- Put your bibliography in a .bib file, not in the Tex file, unless the publisher requires it.
- Your .bib file should only contain the references you need for the paper, not the results of all the literature you have collected since the dawn of time.
- Some journals and conferences try to insist on submissions prepared using a product sold by a global moloch located in the Pacific northwest of the United States. Don't let yourself be intimidated: complain; object; respond that workers in science and engineering have no need for software with a half-life shorter than that of fermium-253[†]; and submit a LaTeX-generated pdf.
- Should you nevertheless be tempted to use one of the popular semi-functional WYSIWYG word processors still occasionally employed, count on your advisor repeatedly "losing" your manuscript or taking a three-year sabbatical in Dagestan before reading your paper.

4 Writing

As reviewer, editor and PhD-student-manuscript-optimizer, I can confidently assert that the fundamental problem with most papers is not mangled grammar or misplaced commas, but rather incomprehensible structure: of individual paragraphs, of sections, and of the paper as a whole. This assertion is as valid for BSc, MSc and PhD theses as for conference abstracts, so practicing good structural discipline during your early paper-writing will help facilitate the ultimate thesis-writing.

[†]Three days

4.1 Overall structure

The purpose of any paper is to describe a specific scientific development. The overall structure of the manuscript should thus typically be as follows:

Introduction A brief introduction to the topic, with a concise overview of the state-of-the-art; you should provide a motivation explaining *why* you undertook this scientific exercise. Relevant earlier work should be adequately referenced, so the reader immediately sees where your work will make a contribution. In the last paragraph of this section, summarize your achievement so the reader knows what is to come.

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

Theory If necessary, the theoretical background on which your experiment, device or system was based. Do not begin with Newton's laws or Maxwell's equations: your reader will be technically competent, but not necessarily in your field of expertise. Do not bother to discuss any theory that you do not employ in later sections.

Fabrication Outline of the technologies used to fabricate and assemble your devices, if applicable. You should provide enough detail so that someone with your level of technical background could repeat your process, but do not go into excessive detail. Figures outlining the process are more helpful than excessive verbiage.

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 paper, 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 earlier work. The reader should understand in this section why your work was a fundamental contribution to the state-of-the-art.

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 overly fatuous prose suggesting your device is the greatest thing since sliced bread.

4.2 Paragraphs

Once you follow this basic outline, the fundamental unit of your text will be the paragraph. Writing a good paragraph is the most important and the most tricky part of generating a readable text. Some guidelines to consider:

- 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.

4.3 Focus, focus, focus: what to put in

Important for the success of your paper (with the reviewers and ultimately with the scientific readership) is a clear focus on the important results. Whereas it is tempting, particularly for journal papers, to include the kitchen sink, only plumbers will find this interesting.

The things which are absolutely essential in your paper, however, are:

- A complete, concrete and clear description of your experiment, device or system
- At least one clear and convincing measurement curve (preferably more than one) showing that your experiment, device or system did exactly what you said it should do
- For purely theoretical papers, a calculation or simulation result showing that your experiment, device or system did exactly what you said it should do
- A convincing discussion of why your result is better than or different from what has been shown before, or that it has never been shown before.

4.4 Focus, focus, focus: what to leave out

As important as what goes into a paper is what should stay out. Remember: forget the kitchen sink, so that the relevance of your advance is not obscured by a fog of irrelevant plumbing. In particular, hit the delete key when you come across:

- An encyclopedic catalogue of references to all proceeding work that somehow used electrons or photons
- Maxwell's, Newton's, Schrödinger's or anyone else's equations that every schoolchild knows
- Any theory which you do not employ later in the paper
- Excessively detailed process descriptions that only a cleanroom technician could love
- Process development, i.e., all the things that *didn't* work
- Friday afternoon measurement results that are cute but ultimately only peripherally related to the focus of the paper
- Conceptual diagrams showing what one *could* do but hasn't really got around to yet.

5 Style

The world does not need another style manual and this isn't one. Yet English is not the native language for many of you and, as a result, you have to pay particular attention to how you assemble your text.

I address here a few issues which come up repeatedly in texts I review, an admittedly personal and idiosyncratic selection. Writing style is a vast mine-riddled field oft characterized by non-productive churlish discourse. For an engaging view, see for example (Pinker, 2014).

5.1 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 5.4

- 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.

- Having said all of this, there are many situations in which the passive voice is preferable, and you will find countless instances in this guide. Think active, but don't shoehorn every phrase into its active form.

5.2 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.

5.3 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)

Obviating boredom with the thesaurus can, however, lead to readers howling with laughter. For example, the reader might grin when imagining angry atoms, since the author wrote that these have been "enraged" by photons; alas, "excited" has a similar meaning, but then again, not exactly. Other readers will certainly chuckle if your chips have been "betrothed" or "fixated" on your substrate; please have your chips "attached" or "fixed" and save betrothal or fixation for your love interest.

- 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.

5.4 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.

5.5 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.

5.6 Things to avoid

There are dozens of details in usage which may be irritating or awkward, or downright wrong. 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 ...".
- In English, you may not combine a verb with an infinitive, such as in "...this *allows to derive* something ..." or "...this *enables to operate* something ...". You should write "...this allows the derivation of something ..." or "...this enables operation at something ...".
- 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.
- Avoid using the abbreviation "e.g."; it is not incorrect but much overused and interrupts the sentence flow. Use a complete sentence with "for example" instead.
- Do not use the word "exemplarily"; it may be a real word, but is often misused by native German speakers. It does not mean "for example"; use that phrase instead.

6 Details

You should adhere to a few rules concerning equations, figures and cross-references. These also contribute to good style.

6.1 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.

6.2 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 sidelobes 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.

6.3 Cross-references

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.

7 The final check

Having digested all these rules, suggestions and admonishments; assembled and collated all your data; written and deleted and rewritten reams of text; and finally assembled a manuscript, you are now the proud parent of a paper describing your work. Take a day off, then read it again, and optimize it a bit.

If English is not your native language, it is essential that a native speaker (or someone with a truly solid command of the language) read and comment on your manuscript before you submit it. If a reviewer rejects your paper because she or he just didn't understand it, that is a waste of everyone's valuable time. So have your manuscript proofread, make a last few corrections, and send it off!

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