Teaching Technical Writing to Science and Engineering Students

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Abstract

The basic principles and most common pitfalls of technical writing for science and engineering students are summarised. It is pointed out that technical writing is integral to the research process itself; it helps the students to organise their thoughts and even potentially discover new directions for their research. It is suggested that a student can improve their technical writing skills by reading many papers/reports from their field, and it is important that, in doing so, they should try to make the connection between the reported results and conclusions. They should not merely think "the authors conclude this or that", but try to establish the bases for these conclusions.

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1. Introduction

Many beginning graduate science and engineering students maintain the high school attitude, "I am good at science and engineering, and all this humanities stuff is boring. I'd like to spend as little time and effort on it as possible". However, the reality is that students cannot become successful scientists or engineers today if they are unable to write. As poor writing obscures the meaning of their message, students may have the best science or engineering results, or project ideas, but if they cannot write a good report, their readers will not be able to grasp their meaning. Therefore, with poor writing, they will not receive either the good marks or the acclaim they deserve from colleagues and lecturers. Moreover, their future careers will be adversely affected if they are not able to describe their thoughts in writing.

To make matters worse, the curricula for science and engineering students are almost entirely focused on specialised subjects (e.g. Sazhin, 1993, 1994, 1998, 1999) or general teaching policy and practice (e.g. Jurkowski, 2018; de Melo & Machado, 2018; Solheim & Opheim, 2018; Thorburn, 2018) with almost no place for teaching them how to prepare technical reports (as one of few exceptions we can mention the paper by Galkin (2018), discussing the teaching of writing to elementary through high school students). At the same time, the importance of technical writing has been widely discussed in the literature (e.g. Doody, 2012; Hall, 2007) although these discussions have almost never reached student audiences.

Most students think writing is something that happens after they finish their projects – as in "write-up the results". They forget that writing is far from being the end product that simply reports upon their work. Writing is how they organise their thoughts, and thus helps them clarify in their own mind what are the key conclusions from that work. After all, a scientific or technical report is not just a collection of figures and statements: "I did this, and this and this and this....". Throughout the report there needs to be a story that is being told. First and foremost, students need to work out what that story is: what are the big open questions that are being addressed, how their work builds upon earlier work in the field, and what exactly their new data or analyses tell them. If, in the process of writing, they find that they are not able to address these questions, then they have to go back and carry out more analysis, or generate new figures. They should repeat this process until they are able to more directly address the questions they are trying to answer. They may also find that their results lead to new questions

or phenomena that they were not aware of at the beginning of the project. Thus, writing is an integral part of the learning process.

Ultimately, for a student's future readers to know what they mean, they must first know what they mean themselves. As they write, they should think about *every single sentence* and ensure that they know what it is they are trying to convey. They also need to bear in mind that all authors, from novices to experienced writers, will produce many drafts in order to achieve the desired clarity of thought and expression. They should never expect to sit down, write something, give it to their lecturers and not have it covered in red ink. The lecturers would not expect that of their own writing!

The main aim of this paper is to share with fellow lecturers our experience of teaching science and engineering students basic writing skills as well as to provide clear guidelines for students to follow. Based upon the experiences of the first co-author (ASS), in teaching science students, and the second co-author (SSS), in teaching engineering students, these skills are almost identical, hence our idea to discuss the teaching of these skill to both groups of students in a single paper. The focus is primarily on students' project reports although the principles discussed in the paper are expected to have a much wider range of application, from laboratory reports to research papers. This paper is essentially based on further development of the unpublished write-up prepared by one of the co-authors (ASS), "Basics of technical writing for astronomy graduate students", focused mainly on astronomy students.

We believe that by following the basic principles described in the paper, students will be able to present clearer, more concise, writing of a professional standard. How much more rewarding would it be if students reviewing a draft report with their lecturers spent less time discussing the need for better grammar and shorter sentences, and more time on science and engineering?

2. Where to begin

Beginning a new report draft can be challenging for students, especially if it is their first attempt. Before they start writing they need to have at least tentative answers to the following questions:

- What are the questions that the report is trying to answer?
- What are the implications of this work compared to prior work?
- What is the evidence for the anticipated conclusions?

It would be helpful if they could actually write down their answers to the above questions. They typically think that they know these answers, but when forced to articulate them, they usually find that they do not understand them as well as they thought they did. If they find themselves unable to write down at least tentative answers to the above, they should discuss their project again with the lecturer before proceeding.

Once they have a reasonable (though not necessarily final) answer to each of the above questions, they should make a project outline. This outline should include the names of sections and subsections (even for those where, as yet, they have no results). It should also include sketches of figures that may be included in each section/subsection. They might also make side notes on what exactly they will try to convey in each section. In other words, the outline is expected to sketch the story they expect to tell the reader (in somewhat more depth than the above questions alone), although the details of the story will likely evolve over time.

Once they have created their outline, they can begin to prepare their first draft. The easiest sections will be the ones where they describe their analysis, so they may as well begin there. They should place any figures they have already produced into the appropriate sections, and write some words that go with them. It is usually suggested that they leave the final introduction to the very end. However, to give them context for their "Results" and "Conclusions" sections, they should write at least a basic introduction which includes the questions their project is trying to answer and presents some of the key literature results. It is likely that the lecturer will need to help new students at this stage, by pointing out to them the most relevant papers. Over time, as the students polish their report, the introductions of these and related papers will give them a good idea of what their own introduction should include. The one section that they can safely leave for later is the abstract (see Section 6).

3. Basic principles

It may seem that if they follow the above described steps the students are almost there. Actually, that is just the beginning. Students should expect to make, many many revisions to their draft, and this is not due to their inexperience! Indeed, the more seasoned a writer they become, the more editing they will find themselves doing. Below we list some basic principles of good writing. As they revise their draft, they should try to follow these

principles as closely as possible. They will help them tell their story in a more clear and concise manner. This will not only benefit their future readers, but most importantly will benefit them. Forcing themselves away from vague, ambiguous prose, towards clarity and objectivity they will come to a better understanding of their own results.

- Students should use correct English – This is often an issue for both native and non-native English speakers (though the pitfalls differ). We suggest that all students familiarise themselves with the contents of one of the many online grammar guides, so that at the very least they know what it covers, and can refer to it when needed. Some useful starting points can be found in (Sagi and Yechiam, 2008; Schmitz et al, 2014).

- Students should omit unnecessary words – By far the most common thing that a lecturer does when editing students' writing is to remove the 'fluff', which can range from unnecessary words to whole sentences. As students write, they should always consider: "Can I say this with fewer words?". Think of it as decluttering.

- Students should learn how to break-up long sentences – This is part of the effort to maintain clarity (see below). There is a tendency for beginners to write long, involved sentences, which typically lose the plot about halfway through. Short, declarative sentences are always better.

- Students should maintain a flow of logic – This is related to the idea that the report should convey a story. More specifically, there should be a clear flow of logic not only from section to section, but also from paragraph to paragraph and within paragraphs.

- Students should be mindful of emphases – If they want to emphasise a particular idea, or result, in their readers' minds, they should consider where it appears. Generally, the last sentence in a paragraph has the greatest impact. Within a given sentence, the thing they want to emphasise should be the subject. For example, notice the difference between: "The infrared-derived star-formation rates are higher than those derived from the UV" vs. "We look at UV- and IR-based star-formation rates and find the latter to be higher".

- Students should convey professionalism – In order to do this, quite apart from its content, a report should employ more formal language than typically spoken English. This means avoiding colloquialisms and expressions of emotional reaction (e.g. *awesome, fascinating, exciting*). On the other hand, reports use words that are not typically used in common speech – e.g. *salient, elucidate, paradigm.* If students are unfamiliar with these (or any other words they find in reports) they should look them up. In time, they will be able to use a wider vocabulary in their own writing which, *used sparingly and appropriately*, makes a good impression.

- Students' prose should be clear – *This is the most important of all basic principles of writing.* Following on from the previous point, while the language in papers is more formal than they may be used to, it should not be unnecessarily heavy. A piece of writing that is nothing but jargon and multi-syllable words will be hard to digest. An author's desire to write more formally should not be at the expense of clarity. The next two points are directly related to the "Be clear" principle.

- Students should define their terms – They should always make it clear how they define a particular parameter, unless it is unambiguous. Any term or parameter in a student report that could be subject to confusion should be explicitly defined.

- Students should be consistent – Once they decide on a particular definition or terminology, they should adhere to it throughout the report. If they begin a report using k for thermal conductivity, they should not suddenly switch to λ.

4. Title, figures and tables

The title is likely the single most important aspect of writing a report. Scientists and engineers typically decide whether or not to read a given report based on its title. Therefore, it has to be relatively brief, understandable outside a narrow specialist field, and it has to give a sense of the key results. In addition, a title that contains grammatical errors or attempts to be funny will not be taken seriously.

Besides the title, the figures and tables are the most looked at aspect of any report. Thus, students should ensure that these alone can convey the

story they are trying to tell. The report should contain a figure in which a reader can clearly see the most important result. Eye-catching figures such as this are likely to boost a student's mark.

Before students generate figures: they should remember that they must almost always have axis labels, and the axis ranges should be consistent with the data range; they should consider the form of display (e.g. linear, logarithmic) that makes the most sense for their data; and they should use large enough character and symbol sizes for easy readability. The style of figure (including line thickness, character font, and character size, as well as meaning of symbols and colours) should be as consistent as possible throughout the report.

The most common mistakes that students make in their tables are giving too many digits (think significant figures), and not specifying the units of their numbers. The crucial function of tables is that they convey the quantitative results of the report. Students should always double and triple check that the values included in their tables are correct.

5. References in the report

Based on our experience, students typically make three types of mistake with regard to references.

- Ignoring references – Some students write their reports as if there were no research in this field before they started working on the problem. Not only must they then re-invent the wheel, but their writing provides no link between their own and previous research in the field. On some occasions this leads to hidden plagiarism when a student describes someone else's idea as if it were their own. This would inevitably be penalised, with the student receiving a lower mark for the report, and could create problems in their future career.

- Presenting a bibliography rather than references – On some occasions student reports have the opposite problem to the one mentioned above; they present a long list of references not directly linked to the text of the report. In this case, the references turn into a bibliography, which might be useful for researchers in the field but is not usually expected in a report. Reports with long lists of irrelevant references appear unfocused and are not expected to attract high marks.

- No or limited links between the references and the text of the report – The most common mistake is that where students present correct and relevant references but fail to link them properly to text of the report. References should not only be presented in the report, but should be closely linked to the text. If this does not happen the whole purpose of using references is lost.

Students should learn to use the style of referencing that is most common to their field (Harvard (used in this paper) or Vancouver styles). They should discuss which this is with their lecturer/adviser.

6. Conclusions and abstract in the report

Once the body of the report has been completed, students can start writing their conclusions. A common mistake when preparing this part of the report is to focus on what they did in their analysis rather than what they achieved. Of course, the analysis process can contain important elements of novelty and in such cases this analysis can be considered as part of the achievement. Basically, students should put themselves in the position of a reader of the report. Any reader would be primarily interested in the contribution to knowledge which follows from the work, the results of which are presented in the report. This should be made as clear as possible in the conclusions.

The student should expect to rework their report a number of times. This involves writing down conclusions, checking that they indeed follow from the body of the report, and editing both the latter and the former until they do. They should keep in mind that being dissatisfied with a first draft and completing multiple iterations is not a sign of a bad writer - it is the mark of a good one!

Either concurrently with the above process or after the final version of the conclusions has been completed, work begins on preparation of the abstract. The abstract should summarise the most essential findings described in the report. This is not just a shortened version of the conclusions. Some important findings described in the conclusions can be omitted from the abstract in order not to distract the reader from the most important findings. This is particularly important when students move from writing reports to writing research papers. If fellow researchers are not convinced that the paper is important, based on a reading of the abstract, they will not bother to read the whole paper.

7. Acknowledgments in the report

The acknowledgments section is the only part which is not linked to the rest of the report. Here, students typically acknowledge the financial supporters of the project (e.g. an industrial company), colleagues who contributed to it, and their supervisor. They can mention family members, but this should be done carefully. Explicit expression of emotion may not be appropriate in a technical report.

8. Software used to write the report

Reports are typically prepared in Word or Latex formats. The first is favoured by engineers and the second by scientists. Both formats have their advantages and limitations. Word is very intuitive and it is easy to learn how to work with this software, but it is not easy to use when one needs to describe complex mathematics. Latex, on the other hand, takes longer to learn, but affords greater flexibility when presenting complex equations and incorporating references in the text of the report. We believe that in the future both engineers and scientists will be using Latex and the rest of this section will be focused on this software (Latex, 2018).

To incorporate references in the report, it is recommended that students use the `\natbib` package and a *.bib file. They can expect to reuse the latter over time and maintaining a good *.bib file will make their life easier in the future. For example, in the case of an astronomy report, their report directory should also have the file apj.bst and the preamble of their document should include the lines:

```
\usepackage{natbib}
\bibliographystyle{apj}
```

Adding references to the *.bib file is very easy in most cases, especially for recently published papers. When the paper contains the icon 'Click for updates, students should click this icon. Then they should click the link following 'Crossref DOI link: and then click 'Export and select 'Export citation to BibTex. Finally, they should copy the information about this publication and paste it into their *.bib file. The only change they will need to make is to change the generic reference to something more meaningful such as 'smith2012. Then they can include the citation in their reports using `\citet{smith2012}` or `\citep{smith2012}`.

In the case of astronomy papers, students can use the NASA/ADS website. Once they find the paper they are interested in, they should click 'Bibtex

entry for this abstract and copy and paste the result into their *.bib file as described above.

Other style issues

- **Value and units** – While the names of quantities are often in italics, the units are expected to be in Roman. Subscripts, referring to abbreviations, should be Roman (using `\rm`) as in $L_{\rm IR} = 10^{12}\,{\rm L}_{\odot}$.
- **Spacing** – Small spaces, `\,`, should be left between numerical values and their units. For example: $m = 5\,{\rm kg}$ not m=5kg. Students should also leave a small space between 'Figure' and 'Table' and the number that follows. In practice, this means using something like: `Table\,\ref{table:photometry}`.
- **Quotation marks** – These should appear as "example" (using `\lq\lq`) and not "example".
- **Single sentence paragraphs** – Students should try to avoid writing paragraphs that consist of a single sentence.

9. Conclusions

The basic principles and most common pitfalls of technical writing for science and engineering students are discussed. These principles are essentially based on George Orwell's (1946) statement: *A scrupulous writer, in every sentence that he writes, will ask himself at least four questions, thus: What am I trying to say? What words will express it? Could I put it more shortly? Have I said anything that is avoidably ugly?*

It is pointed out that technical writing is integral to the research process – it is the means by which students organise their thoughts and even potentially discover new directions for their work. This process is particularly challenging for beginning students. The best way to improve is by reading many, many reports in their field. When reading them, they should try to make connections between a report's results (for example as expressed in its figures) and its conclusions. They should not merely think "the authors conclude X,Y,Z", but rather what is their basis for these conclusions? Do students believe them? Why, or why not? By seeing multiple examples of how the story is told in these documents, from introduction to conclusion,

they will be better equipped to tackle their own reports. As with all forms of writing, the more they read, the better they will become.

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