

Beginnings and Endings: Keys to Better Engineering Technical Writing

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Abstract—Engineers face many technical writing tasks that have many features in common: title, abstract, introduction, problem formulation, methods, results, and conclusions. But it is often very difficult to actually write these segments in the same order they appear in the finished product. Instead of this linear approach, we recommend a modular approach starting with the core sections, the methods and results that researchers know best, and working backward and forward to pick up the beginnings and endings. We show how the beginning and ending sections build on the core sections and offer strategies to improve them.

Index Terms—Abstracts, conclusions, introductions, modular writing approach, technical writing strategies, titles.

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CONVENTIONAL wisdom says that engineers as a group dread writing. Yet the results of a recent survey of practicing aerospace engineers and scientists [1] show that practicing engineers spend a significant portion of their time creating their own technical documents or working on those of others. For example, “the average number of hours spent per week producing technical communications varied from a mean low of 19.6 hours to a mean high of 23.3 hours,” depending whether the engineers worked in design or development, “and a mean low of 14.9 to a mean high of 19.6 hours” if they worked on technical communications received from others. Add to that engineering academics who write proposals, journal articles, project reports, and conference papers, to say nothing of lectures and class handouts, and we see that the need to write well is pervasive.

Engineering and writing have been inextricably linked from the early Roman times [2] as shown in the earliest translations of the Roman architect Vitruvius [3] and of the

Roman engineer Frontinus [4]. Both stressed the need to keep a written record of what had been done so that those who came later could follow their steps. Early in this century, the famous scientist Charles Steinmetz [5] had a particularly clear view of the value of good engineering writing. He was concerned among other things with how well research reports communicate knowledge to particular audiences. Even these early engineers felt responsible not only for practicing engineering but also for documenting it and making their knowledge available to others. That goal is still important today and is amplified by the knowledge that how well engineers conduct research, write, and publish has a great impact on the advancement of their careers as well as on the advancement of knowledge.

While the fields of engineering and the language to discuss them have expanded enormously over the centuries, the need to communicate engineering knowledge is still at the heart of the engineering profession both in industry and academia. We

want to look at the major problems we see in the technical papers we edit as the editor of an international scientific journal and as a technical editor in an engineering college. We first consider the overall writing process and how to get started. Then we explore the four parts of technical writing that seem to give authors the most difficulty: title, abstract, introduction, and conclusions. These beginnings and endings play a critical role in the overall success of any technical paper [6], [7]. Our recommendation is to adopt a modular approach for writing a technical report or article. By that we mean to pull the sections out of their normal order and work on them in the order of ease for the author. The discussion focuses on determining the purpose of each of these beginning and ending components, the order in which they might be written, and strategies for writing each one.

GETTING STARTED

J. H. Mitchell [8] says that "most research and writing projects begin with a problem and end with a solution." Thus to get started, writers need to develop a working problem statement. This is simply a qualitative statement of the main message or messages in the paper under construction. What will the publication of this paper accomplish? For instance, we might state the problem for this paper as follows: researchers frequently have trouble writing technical papers because they get bogged down in the beginnings and endings. Such a working problem statement will help keep the writer focused on the main objective while working on each of the components.

With a working problem statement in hand, researchers can do the literature review and examine what people currently know and where the issues are. Until researchers know something about past work, they will find planning the research, assessing how their ideas fit with previous work, and determining the

likely contributions difficult at best. Abstracting journals are the place to start. A subject search gives the scope and key players on any given topic. From there, an author search will yield the specific articles most likely to be of interest. Checking the references in these articles will likely add a number of other authors and titles of interest.

After researchers have compiled a list of articles, the next question is how to deal with them. Before writing can begin, information must be gathered and thoughts assembled. One method we find helpful in the beginning stages of writing is to label a piece of paper or a computer file with the various sections of the paper. Generally, researchers know what should be included in a technical paper: 1) title, 2) abstract, 3) introduction, 4) problem formulation, 5) methods, 6) conclusions, and 7) references. The task is to enter salient points or quotes from the literature under the proper heading with bibliographic information noted. The order of the information under each heading is not critical at this point because entries can be rearranged later.

Once the notes are taken, researchers typically think that the best way to write the paper is to start at the beginning and write till they come to the end. That approach is a logical and linear way to think, but it is not necessarily the most effective way to work through the writing process. Facing a blank piece of paper labeled introduction or abstract can be daunting. Rather we recommend a modular approach in which we separate the sections of the paper and work on them in the order that is easiest for the writer.

METHODS AND RESULTS

When the research or project is complete, researchers know the most about the problem that has just been solved, the methods used to solve it, and the results achieved. Thus it seems auspicious to begin with the problem formulation

and the methods used to solve the problem—What worked? What didn't? and Why?—and describe the process used to get to a solution. Reviewing their laboratory notebooks or computer files shows how they tackled the problem—the false starts, the twists and turns, and the triumphs. Beginning with what they know best gets writers off dead center and into the fray. At this creative stage, writers do not need to worry too much about the grammar, but rather they need to concentrate on tracking the research.

When a draft of the methods is complete, writers can go on to the next section and show the results achieved. The questions they need to ask themselves include: What did I find out that I didn't know before? What do the data indicate? How do my results compare with those of others? After these questions are answered, writers need to go back to the laboratory notebook or computer files to document the results. Tables and figures can be used to display the results and to show comparisons with other methods. Once a draft of the results is finished, the bulk of the paper is well under way. This achievement will give writers the confidence to tackle the next section, which might be either the introduction or conclusions.

WRITING THE INTRODUCTION

For many situations, the introduction will be the best place to start. The purpose of the introduction is to encourage the reader to read the whole article. It explains why there is a need or a problem and how the author will deal with it. The introduction usually motivates the present study, provides a literature review, and explains how the current work fits with what has gone before. In addition, a brief summary of the findings is frequently included. What better time to write the introduction than when the results section has just been completed. The importance of the work and how it fits in with the

larger scheme of research in this area should be the clearest at this time.

Much has been written about the function of introductions. Menzel, Jones, and Boyd [9] indicate that “the first sentence of the introduction is a kind of a road map, a brief indication of the direction the argument will take and the nature of the goal.” Rada [10], on the other hand, touts the role of introductions as assuring the likelihood that a reader will move on to the body of the article. Miles [11] states that the introduction “usually gives an overview of the problem confronted, the theory behind the methodology used, and a statement about the significance or importance of the current research,” while Mills and Walter [12] cite four specific functions of the technical introduction: to state the subject, purpose, scope, and plan of development.

The common themes in the literature indicate that the introduction contains the problem statement, shows what has been done on the problem in the past, and relates the current work to past history. As writers do research, they are all indebted to the researchers who have preceded them. We like to think of this progression of knowledge as a pyramid, with each higher level resting on the base of the previous one. If the research area is well-developed, writers can cite survey papers for the earlier works and then spend more time reviewing the last ten years of research. Having shown their place on this pyramid, they can indicate their methods of development and indicate briefly what they have found. Questions for writers to ask themselves include: Is my approach an incremental contribution or a new way of approaching the problem? Specifically, how does my work differ from previously published work? Be explicit about this; do not make the reader guess what is new. End the introduction by stating the importance of the research.

Some authors, such as Mills and Walter [12], recommend including the organization of the paper. For example, “This report will be divided into five major parts:...” While perhaps useful for a long report, this information already appears in the table of contents. We do not recommend that writers end the introduction with such a paragraph unless the guidelines call for it. Such a paragraph is a weak ending to an important section; it is usually filler and does not advance the work. A better method is to end the introduction with a clear statement of the importance of the research and then use subheadings to indicate the structure of the remainder of the paper.

WRITING THE CONCLUSIONS

When the introduction has been drafted, the next section to tackle is the conclusions. Writers have written about their vision of the project, the methods they have used, and the results they have obtained. Now it is time for them to step back, ask themselves the following questions, and assess what they have learned. What does the research mean? Why is it significant? What contributions does it make, i.e., what value has it added to the body of knowledge in the field? How will others be able to use it? Where do we go from here?

Authors of technical writing books and technical society publication guides offer a variety of thoughts on the function of conclusions. For example, Marder [13] notes that “conclusions give a sense of completion to the report” and “conclusions and recommendations (either positive or negative) comprise the value received for the money spent.” “Conclusions,” notes the American Institute of Physics [14], “are convictions based on evidence. If you state conclusions, make certain that they follow logically from data you presented in the paper, and that they agree with what you promised in the introduction.” Lannon [15] lists the functions of conclusions as a “summary of information in the

body, comprehensive interpretation of information in the body, and recommendations and proposals based on the information in the body.”

From our perspective, authors need to make a distinction between a summary that deals with the process of the research and a conclusion that focuses on the contributions of the research. For a long report, writers may want to summarize the work briefly and then analyze the significance of the research in a final section titled Summary and Conclusions. However, a conclusion should not simply restate what was done, and writers should avoid the trap of repeating a lot of what was stated in the introduction. Thus the summary ought to be kept to a minimum and instead the emphasis should be placed on interpreting the results and especially on identifying the contributions. It may be advantageous to list the main conclusions with bullets or numbers so that readers can identify them immediately.

Most journal articles should not include a summary. Rather the conclusions should delineate the significance of the research. What do we know now that we did not know at the beginning? How good are the results? Writers should be as quantitative as possible when they state their conclusions. For example, use “The XYZ method achieved a 15.7% reduction in manufacturing time,” rather than “the XYZ method works well.” The IEEE Power Engineering Society [16] suggests several additional questions for authors to answer at the end of the conclusions: “What are the advantages and limitations of the work?” and “What are the recommendations for further work?” Perhaps the paper has several small contributions or maybe a big one. Whichever it is, the conclusions section is the place to wrap up the package and deliver it to the reader.

DEVELOPING A TITLE

The title provides the first hook for the reader. Not only are titles important for their content but also for their visibility, especially when they appear in an abstracting journal. Finding the right words and phrases is crucial to bringing the reader into the article itself. Our strategy for writing titles is to jot down key words and play with them to see how they might go together. While writing the paper, we keep a list of alternatives so that a number of possible titles are available, either to use as is or as a springboard for a new title.

What makes a good title? Make it short and make it snappy sums up the thinking of many technical communicators [9], [17]. An exception is Jones [18], who indicates that unlike literary books, whose titles are short to arouse interest, report titles are primarily informative and concerned more with completeness than conciseness. He does advocate being as brief as possible, but up to 40 or 50 words may be used. Many other technical writers advise making the title brief while still descriptive. Marder [13], for example, suggests that a title "is a phrase announcing the essence of the report," but it should not be a summary of the report's contents. Since many journals limit the length of titles, authors should check the guidelines. Even if guidelines pose no restrictions, a good goal for title length is recommended by the American Mathematical Society [19], which asserts that "A title of more than ten or twelve words is likely to be miscopied, misquoted, distorted, and cursed." Jones [18] also suggests that the title may begin with the words "Report on..." or "A Study of..." Most current writers on technical writing recommend instead using key words to start the title [9], [17]. The American Mathematical Society [19] is more explicit than that when they advise authors to "make the title as informative as possible, but avoid redundancy, and eschew the medieval practice of

letting the title serve as an inflated advertisement."

To shorten a draft title, cut the words that are not essential. As an example, consider the title, "An Investigation into the Effects of Residential Air-Conditioning Maintenance in Reducing the Demand for Electrical Energy." Clearly, the author is considering the relationship between residential air conditioning maintenance and electric power demand. A more compact title would simply be "Role of Air-Conditioning Maintenance on Electric Power Demand." This new title reflects the relationship between the two parts of the subject and reduces the number of words by half.

Most importantly, the title should reflect the focus of the paper and allow an editor to place the paper in the appropriate category in an abstracting journal, conference attendees to know whether they want to hear the paper, or managers to know if a particular report is of interest for the problem at hand. Titles then are critical—they need to have the keywords that will help a researcher make the first cut, e.g., is the paper about linear or nonlinear programming? control theory? artificial neural networks? Also pick some of the title words to distinguish your work from previous papers. For example, if in the past a particular problem has only been solved using linear methods and you are solving the problem with nonlinear methods, make sure you include the word *nonlinear* in your title. Consider inventing a new word to make your title stand out, e.g., "Optimal Aerocapture Trajectories"—aerocapture is not in the dictionary, but it conveys the main focus of the paper.

Once a title is chosen, take time to proofread it and check for spelling, grammar, and capitalization. For example, "articles (a, an, the), coordinating conjunctions (and, but, or, for, nor) and prepositions, regardless of length, are lowercased unless they are the first or last word of the

title or subtitle. The *to* in infinitives is also lowercased" [20].

WRITING THE ABSTRACT

Abstracts are often the hardest part to write and yet are the most important. Thus we recommend leaving it till last so writers have their whole text in front of them. Abstracts play a role both within the paper and outside it. As part of the paper, abstracts give a brief overview and help the reader know and judge the value of a particular piece of scientific writing. Outside the paper, the abstract serves as a filter for classifying papers. Abstracts of journal articles appear in abstracting journals and in this form they help readers decide if they want to see the whole paper or not. For reports, the abstract gives the first clue to an agency whether the work is worthwhile and whether they will look beyond the abstract. To get a paper read, authors must take great care to give enough information in the appropriate language (buzz words if you will) so that researchers can quickly decide if they will read the full paper.

Authors writing about abstracts provide a variety of recommendations. Menzel, Jones, and Boyd [9] admonish writers "to present a clear, concise summary, preferably in one paragraph, of the purpose and most important results of the investigation together with a minimum of the theory it is based on" to be used in abstracting journals. Booth [17] advises authors "to state briefly what you did. Then the main results, ... State the conclusion in the last sentence." Marder [13] calls abstracts a "thumbnail (sketch) of the report itself."

Regardless of the words used to describe an abstract, the abstract is critical in getting a researcher's work out to the scientific community. In our view, the abstract contains some elements of an introduction, problem statement, methods, results, and conclusions. A

sentence for each of the main areas may be all that is needed. The abstract may be quite brief, perhaps 100–200 words or less. This means the writer has to be concise. Also the writer should state the relevant facts as objectively as possible and avoid self-praise and overt advertising. We like to think of writing an abstract as including five parts: 1) the context of the work, 2) the problem statement—specifically what the scope is, 3) the methods—how the work was done, 4) the results—what discoveries were made, and 5) the conclusions—the significance and contributions of the work.

In writing abstracts, do not include references; the abstract should be able to stand alone. Likewise, avoid acronyms unless the word or word cluster is cumbersome and is used more than once. Then identify it the first time it is used in the abstract and again the first time it is used in the body of the paper.

CONCLUSION

Writing a technical paper using a modular approach is not the norm, but it does have some advantages. Writing first what a researcher knows best builds confidence and gets the creative juices flowing. By the time researchers get to the tougher sections, such as the abstract, most of the ideas that they need are already in hand. The task then is to pick out these salient points and key words and weave them together to tell the story in miniature.

If writers stopped with discrete modules, of course, the paper might not hold together as an organic whole. Therefore, the writer's last task, once all the sections are in place, is to look critically at how they fit together. Questions to ask include: Does each section perform its appointed task? Is the order logical? Do the ideas flow together or are better transitions needed? Does the same material appear more than once? Can the writing be tightened and made clearer? Does the writing fit the audience? For example, if it is for technical peers, is the background condensed and the methods, results, and conclusions amplified? If it is for the boss in industry, is the problem statement clear and the big picture painted in broad strokes? Is there enough detail to back up the generalities but not so much as to discourage the reader? Does the title contain the key words that will hook the reader?

We have talked little about the quality of the writing itself because that is not our primary focus here. But since the quality of the writing is very important, we offer a suggestion for writers once they have done their best. That is to ask for some peer review from colleagues or an editorial service. Getting feedback from an impartial reader will help a writer see the places where readers go astray and where reader's questions are unanswered.

The format of the paper is another detail that needs attention. If you are writing a journal article, consult the journal to see how they

want the document to appear. Pay attention to heading styles and how references should be cited and listed. These guidelines will also specify number of pages, how to deal with tables and figures, and so on. Putting your paper in the recommended format is a subtle way of saying to the editor that this paper is prepared especially for that journal. These details **are** noticed by journal editors.

As we take a long view of technical articles, we see that the writer has three key places to hook the reader—each one reveals a little more about the topic, like layers of an onion: for example, 1) the title gives readers key words to catch their interest; 2) the abstract gives a mini overview of the whole paper, kind of a teaser that gives more detail than the title; and 3) the introduction gives the scope of the problem and the objectives of the research, the background and how it relates to past work, and the nature of the data and analysis. Along with the conclusions, these beginnings are crucial for engaging readers' attention. Most seasoned researchers do not read all papers straight through. They start with the title, of course, then the abstract, the conclusions, a quick scan of the references, next the introduction, and then maybe on to the body of the paper. Will the beginnings and endings of your paper survive this sequence of inspection? Writers who can master these sections will boost their chances of publishing their articles and having others read them.

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