Chapter 2
Structure and Organization

Writing is inherently a creative process. That would seem a good fit for the science researcher, where creativity coupled with critical thinking is the key to success. Alas, many scientists do not think of themselves as qualified writers, finding the task of writing both intimidating and arduous. For those readers who are not already experienced at writing articles for scientific journals, I have a secret to share: you do not have to be a good writer to write a good scientific paper. The reason is this: there is a formula for how to structure and organize a scientific paper, so that the scientist/writer can focus on what they know best—the science—and worry less about the writing.

A formula for writing may sound like a recipe for mediocrity, and in some contexts this would surely be true. But for the scientific paper, the emphasis must always stay on the science, with the words mere tools for effectively conveying information. Over the last 350 years, scientific journals have evolved a distinctive style, structure, and organization that make it easy for both the writer and the reader to get what they need from the paper: effective communication of scientific ideas.

A major difference between journal-based science writing and the diverse forms of writing found elsewhere is the very limited scope of our medium. A scientific paper does not have to be all things to all people. It is a narrow genre with a narrow (though very important) purpose. A specific scientific community is not a random sampling of humanity but a group that shares an established and understood basic scientific background, a broadly agreed-upon set of common goals, and an already established set of mechanisms for the communication of information. By following the standard structure and organization of a science research article, the author is constrained in many respects. But these constraints free the author and the reader to focus on the content, which often results in a better paper.

2.1 The Standard Structure of a Scientific Paper

The vast majority of papers published in scientific journals today follow a fairly simple structure. With some variations, most papers use an “IMRaD” format:

Introduction
Method (experiment, theory, design, model)
Results and Discussion
Conclusions

This format is so ubiquitous that it is often surprising to see a paper that significantly deviates from it. (Outside of the field of science, this organizational model goes by the acronym CEC: claim, evidence, commentary.) Of course, there are many variations on this theme, and the structure is meant to advance the goal of communication, never hinder it. There are two main advantages of following the IMRaD structure: it makes it easier for the writer to organize the content of the paper, and it makes it easier for the reader to opportunistically find the information they seek. The following sections look at each of these standard sections in more detail.

2.2 Introduction

In standard rhetoric, the Introduction section should answer two questions: "What?" and "So what?" What is the paper about, and why should the reader care? The scientific journal paper is a specialized form of rhetoric, and so we use a more specialized format for our introduction, but answering these two questions is still required. Thus, an introduction should inform the reader as to what the paper is about and motivate the reader to continue reading.

As will be discussed in Chapter 7, a paper must meet four criteria before it is publishable in a scientific journal:

- The content of the paper must match the scope of the journal.
- The quality of the paper (method and execution of the research, as well as the writing) must be sufficiently high.
- It must present novel results (with the exception of review papers and the like).
- The results must be significant enough to be worth reading (and thus worth publishing).

Of these four criteria, the author should clearly lay claim to three of these in the introduction (scope, novelty, and significance). Quality is implied and should be demonstrated, not explicitly claimed.

The basic flow of the introduction starts with the general and then moves to the specific. As Swales has described it, the research-article introduction moves through three phases:[1]

- Establish a territory (what is the field of the work, why is this field important, what has already been done?),
- Establish a niche (indicate a gap, raise a question, or challenge prior work in this territory), and

- Occupy that niche (outline the purpose and announce the present research; optionally summarize the results).

An alternative formulation of these three parts of the introduction uses topic, problem, solution (for engineering); or topic, observation/discovery, explanation (for science). Some articles finish the introduction by presenting an outline of the article, although I am not a fan of this style. The section headings themselves are more effective than creating a table of contents in prose form.

Some common pitfalls in writing an introduction include providing unnecessary background information (telling the reader what they already know or what they do not need to know), exaggerating the importance of the work, or failing to make clear what research questions this paper is trying to answer.

2.3 Method

The Method section (sometimes called the Materials and Method section) describes how the results were generated. It should be sufficiently detailed so that an independent researcher working in the same field could reproduce the results sufficiently to allow validation of the conclusions. Often, this does not require explicit step-by-step instructions but rather references to prior publications that provide such details. For some research articles, it is the method that is novel. For this case, a much more detailed description is required. For standard or well-established methods, naming the method may be sufficient.

Let us parse the requirement for "sufficient detail" a little more carefully. There are really two interrelated goals at work: the reader should be given the ability to reproduce the results and the ability to judge the results.[2] Although very few readers attempt a replication of another's experiment, most careful readers attempt to judge the validity of the work they are reading. Internal validity means the conclusions drawn are supported by the results presented. External validity refers to the degree that the conclusions can be generalized (rather than being applicable only to the narrow confines of this one work). Without a carefully written method section, it becomes impossible to assess the validity of the work.

A "method" is used here more broadly than an experimental method. The method can include the development of a theory (either as necessary background or as a novel element of the paper), the establishment of a specific device design, or the development or description of a modeling tool to be used. A common variation of the IMRaD structure separates the theory (or design or modeling) into its own preceding section before moving on to the experimental method.

A good method section should not only describe what was done and how it was done, but it should justify the experimental design as well. Of the many options available, why was this method chosen? Statistical considerations, such as sampling plans and analysis methods used, should be explained. If the raw results are not going to be presented, then a description of the data-reduction procedures is required. Also, consider how a figure or diagram might be used to illustrate or summarize the methods.

A common shortcoming of method sections in many papers today is the abandonment of the goal of reproducibility. Usually citing economy as the driving principle, method sections are often overly brief and lacking in detail. Rarely does a method section explain why one approach was chosen over another. Nobody reproduces other people's work anymore, or so the thought goes. I find this attitude mistaken and often self-serving. Some researchers may not want their results to be reproduced, and more to the point, may not want the validity of their results to be questioned. Others may want to hide necessary details for commercial reasons. But the advancement of scientific knowledge requires both reproducibility and the ability to judge the quality and validity of published results. A thorough and detailed method section is the first and most important step in achieving these two goals.

Other common pitfalls when writing the Method section: including results in the Method section, including extraneous details (unnecessary to enable reproducibility or judge validity), or treating the method as a chronological history of what happened.

2.4 Results and Discussion

The results of a paper, if included as its own section, should be very short. It is simply a presentation of the results obtained corresponding to the methods described in the previous section, organized to make them accessible to the reader. Often, these results are presented in tables and/or graphs. Well-crafted tables and figures require very little in terms of supporting text in the body of the paper (see Chapter 4), so the results are usually combined with a discussion of them in the results and discussion section. An important goal when presenting results is to clearly designate those results that are new (never before published), while properly citing results that have been previously published.

Evidence does not explain itself. The purpose of the Discussion section is to explain the results and show how they help to answer the research questions posed in the introduction. This discussion generally passes through the stages of summarizing the results, discussing whether results are expected or unexpected, comparing these results to previous work, interpreting and explaining the results (often by comparison to a theory or model), and hypothesizing about their generality.[3]

The Discussion section inverts the format of the introduction, moving from the specific (the results generated in this work) to the general (how these results demonstrate a general principle that is more widely applicable). Any problems or shortcomings encountered during the course of the work should also be discussed, especially if they might influence how results are to be interpreted.

Some common pitfalls when writing the results and discussion section are a lack of organization, presenting results that are never discussed, presenting discussion that does not relate to any of the results, presenting results and discussion in chronological order rather than logical order, ignoring results that do not support the conclusions, or drawing conclusions from results without sound logical arguments to back them up.

2.5 Conclusions

The Conclusions section provides a brief summary of the results and discussion, but it should be more than a summary. After showing how each research question posed in the introduction has been addressed, the implications of the findings should be emphasized, explaining how the work is significant. The goal here is to provide the most general claims that can be supported by the evidence. This section should be reader-focused, avoiding a list of all the things that "I" or "we" have accomplished.

The Conclusions section should allow for opportunistic reading. When writing this section, imagine a reader who reads the introduction, skims through the figures, then jumps to the conclusion. The conclusion should concisely provide the key message(s) the author wishes to convey. It should not repeat the arguments made in the results and discussion, only the final and most general conclusions. While the results and discussion section is often quite long, the conclusion section is generally short.

The second goal of the conclusion is to provide a future perspective on the work. This could be recommendations to the audience or a roadmap for future work. A small amount of speculation can be appropriate here, so long as it is relevant and clearly labeled as speculative.

Some common pitfalls when writing the conclusion are repeating the abstract, repeating background information from the introduction, introducing new evidence or new arguments not found in the results and discussion, repeating the arguments made in the results and discussion, or failing to address all of the research questions set out in the introduction. Because a conclusion should be more than just a summary, I prefer "Conclusions" as a title for this section over "Summary."

2.6 The Structures of Papers in the *Journal of Micro/Nanolithography, MEMS, and MOEMS*

To explore whether the IMRaD structure is commonly used in my community, I examined the 100 papers published in the *Journal of Micro/Nanolithography, MEMS, and MOEMS* (JM^3) in 2013. I found that 78% of them employed some variation of the standard IMRaD organization. About half of these separated the theory from the Method section, which was the most common variant. Other variants included separating the motivation from the introduction, separating future work from conclusions, separating results from discussion, and dividing a long section (such as theory or discussion) into separate parts. Only one paper did not have an introduction section, and only one (different) paper did not have a conclusion section. The 22% that did not employ the IMRaD structure generally employed a structure that was more specific to that work, using descriptive headings that did not fall into the "methods" or "results and discussion" categories. One interesting structure created two parallel sets of sections, one for experiment and one for modeling.

Headings and subheadings are an important part of a paper's organization. Headings are almost always required in science journals, but subheadings are often optional. Still, 88% of JM[3] papers in 2013 used subheadings. About half (49%) of the papers used generic headings (Introduction, Method, Results and Discussion, etc.), whereas the rest used substantive headings, changing the text of the heading to be specific to the topic of the paper. There are also optional sections found in many JM[3] papers: 79% of the papers I looked at had an Acknowledgments section, and 5% had one or more appendices.

2.7 Conclusions

(Let us see if I can follow my own advice about conclusions.)

Not everyone is good at writing, either by nature or inclination. For those of us who don't moonlight by writing articles for *The New Yorker* or *Vanity Fair*, writing a good scientific journal article is still within our grasp. One very helpful tool is to organize your paper according to the IMRaD model and follow the general advice listed earlier. Of course, if the nature of your work demands a different structure, feel free to change and invent. But most of the time, structuring your paper according to the standard organization most commonly used in science journals makes the writer's job easier and the reader's time more effective.

References

[1] J. M. Swales, *Genre Analysis: English in Academic and Research Settings*, pp. 140–166, Cambridge University Press, Cambridge, England (1990).
[2] L. F. Azevedo et al., "How to write a scientific paper – Writing the methods section", *Rev. Port. Pneumol.* **17**(5), 232–238 (2011).
[3] J. M. Swales, *Genre Analysis: English in Academic and Research Settings*, 172–173, Cambridge University Press, Cambridge, England (1990).