EIGHT

The Canonical Structure of the Scientific Paper

The canonical structure of the modern scientific paper is familiar to anyone who has even dipped a toe into the literature. It's often labelled "IMRaD," for *I*ntroduction, *M*ethods, *R*esults, *a*nd *D*iscussion, because it includes those elements in that order (with each section containing a rather standard set of components). This canon represents a consensus among scientists about the most effective way to package information, and it's extremely helpful for both the writer and the reader. It hasn't always been this way, though, and it's worth thinking about why.

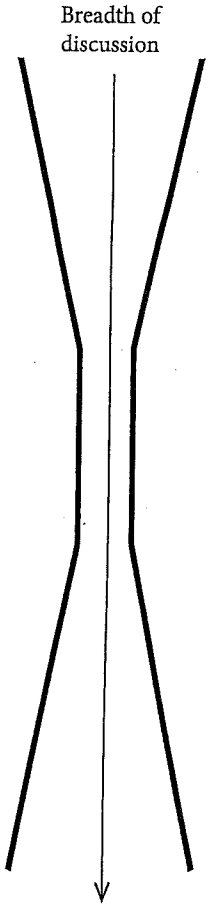
The Evolution of Canonical Structure

If you browse seventeenth- and eighteenth-century issues of the *Philosophical Transactions*, you'll find that the earliest scientific papers held to no discernible conventions of structure, format, or style. Some were written as letters (right down to salutations and signatures), while others were travelogues, descriptions, or narratives. Few papers had section headings or other formal structuring, and in those that did, sectioning was idiosyncratic. Literature citations might appear in the margins, as footnotes, as endnotes, in the text, or not at all. Figures and tables were rare, often unlabelled and unnumbered, and often printed at the end of a volume rather than with the paper that referred to them.

Reading this early literature can be very entertaining, but it can also be frustrating and bewildering. Each paper takes its own approach, and it's often not obvious what story is being told and how. This probably wasn't fatal to the writers' aspirations to be read, as the literature at the

time was manageably sized and someone could fairly easily read everything published on a topic as broad as "chemistry." Through the nineteenth century, however, the professionalization of science pushed writing away from the descriptive, personal style of the earliest publications. At the same time, the rising volume of published work made readers less patient. In the 1830s and 1840s, an organizational style including elements we would now recognize as Introduction, Methods, Results, and Discussion (Harmon and Gross 2007) became common, especially in German chemistry papers, although these were not necessarily separated and labelled as sections. Detailed methodology became particularly important in work by early microbiologists (such as Louis Pasteur) in support of the germ theory of disease and in rejection of spontaneous generation, and so a separate section for Methods became common (Day and Gastel 2006). However, only in the mid-twentieth century did papers take their fully modern form, with the explosive growth of research and publication during World War II and the space and arms races of the 1950s and 1960s. Journals began to insist on standardized structures with separate and labelled Abstract, Introduction, Methods, Results, and Discussion sections, in part to ease the burden on editors, reviewers, and readers.

The canonical structure we now use evolved to allow efficient access by readers to the content of a scientific paper. Our familiar conventions work as a "finding system" (Gross et al. 2002) in which writers meet well-defined reader expectations: someone wanting to know how an experiment was done can proceed directly to the Methods section; someone wanting a summary of the research question can look to the end of the Introduction; and someone wanting to know why the results are important can check the end of the Discussion. This allows readers to access specific information without having to read the whole paper, but it also assists the start-to-finish reader because it presents information in a familiar order designed to draw that reader inexorably through the paper's story to its conclusion. Finally, the headings, figure numbers, and other organizational features signal the reader's place in the story. Not every paper can take the IMRaD structure (chapter 16), but for those that can, the canonical structure is a powerful tool for achieving crystal-clear communication with the reader.



Front Matter
- *Title*
- *Byline and author affiliations*
- *Keywords, word counts, and other details*

Abstract

Introduction
- General context of the work
- Narrower research area and statement of its importance
- Identification of a gap or other need for research
- Specific research question meeting the identified need
- Summary of approach to answer the research question
- Announcement of principal findings

Methods
- Materials, species, field sites, mathematical techniques, etc. used in the research
- Observational/experimental procedures followed
- Methods for analysis of data

Results
- Results of observations, experiments, or modeling in text, tables, and/or figures
- Comparisons among results (e.g., observation vs. theory or treatment vs. control)

Discussion
- Interpretation of results to answer research questions
- Consideration of possible weaknesses
- Relationship of results to previous literature and broader implications of having answered research question
- Prospects for future progress

Back Matter
- *Acknowledgements*
- *References cited*
- *Appendices or online supplements*
- *Data archives*

Figure 8.1 Canonical structure of the modern scientific paper. Sections in black ("IMRaD") are the core elements that tell the paper's story. Sections in *italics* are supporting materials with other functions.

The Canon: "IMRaD" Structure and the Hourglass

The familiar "IMRaD" structure (Figure 8.1) is actually a bit more complicated than its acronym, for three reasons. First, the four major sections are the core of the paper but are surrounded by other elements. The core sections are always preceded by front matter (title, bylines, and other administrative details) and usually by an Abstract; and they are always followed by some back matter (acknowledgements, references, and/or appendices or online supplements). Second, each of the four major sections also has some standardized substructure. Third, there is some minor variation in presentation of the Results and Discussion sections: they are usually (and best) kept separate, but sometimes combined; and the Discussion is sometimes followed by a separate Conclusions section. Nevertheless, IMRaD is the skeleton on which nearly every paper is built.

The IMRaD core has an important property, illustrated by the hourglass shape in Figure 8.1. A well-written paper follows a predictable change in focus: broad attention to the work's context in a major field at the beginning of the Introduction, narrower definition of the central research question at the Introduction's end, narrowest focus on specific techniques and results at the hourglass's middle in the Methods and Results, and broad context again at the end of the Discussion. The broad beginning and ending sell the story (chapter 7) to the largest possible set of readers, while the narrowing through the Introduction defines that story and identifies precisely how the writer will answer the central research question. Keeping the hourglass shape in mind will help enormously in writing effective Introduction and Discussion sections.

Over the next several chapters, I focus on each section in turn. I present them in their order of appearance in the finished manuscript, but remember that few writers will tackle them in this order (chapters 5 and 7).

Chapter Summary

- The IMRaD structure is now standard for most scientific papers, and includes Abstract, Introduction, Methods, Results, and Discussion

- IMRaD functions as a "finding system" for readers, allowing efficient access to content.
- A well-organized paper will have an "hourglass" structure, with focus broad at the beginning, narrowing through the Introduction, and widening again through the Discussion.

NINE

Front Matter and Abstract

Because the IMRaD core of your paper tells its story, it's tempting to dismiss the rest of the paper—front matter and back matter—as unimportant. This would be a mistake. Together, these additional elements connect your work to the larger literature and the larger scientific community. They provide summary and indexing material so that interested readers can find the work (and its authors) and so that editors can deal with it appropriately in review. Finally, they let you supplement your core story with additional material that can be accessed by others who wish to expand on what you've done. So although front and back matter may be easily written, they should not be treated lightly.

Title

Every paper begins with a title. Its function is advertisement: it invites a potential reader to pick up your paper and read further. Like a pickup line, a title needs to do its work quickly: someone scanning a list of papers may decide whether or not to read yours based on just a few seconds' glance.

To be effective in its advertising function, your title should be brief, clear, and informative. It should communicate your paper's story, or at least its central question; in fact, you could think of your title as the shortest possible summary of your paper. The obvious tension between keeping a title brief and having it summarize your entire paper accounts for the high frequency of "colon titles": longer titles broken by a colon into a more general opening phrase or clause and a following one, usually more tightly focused.