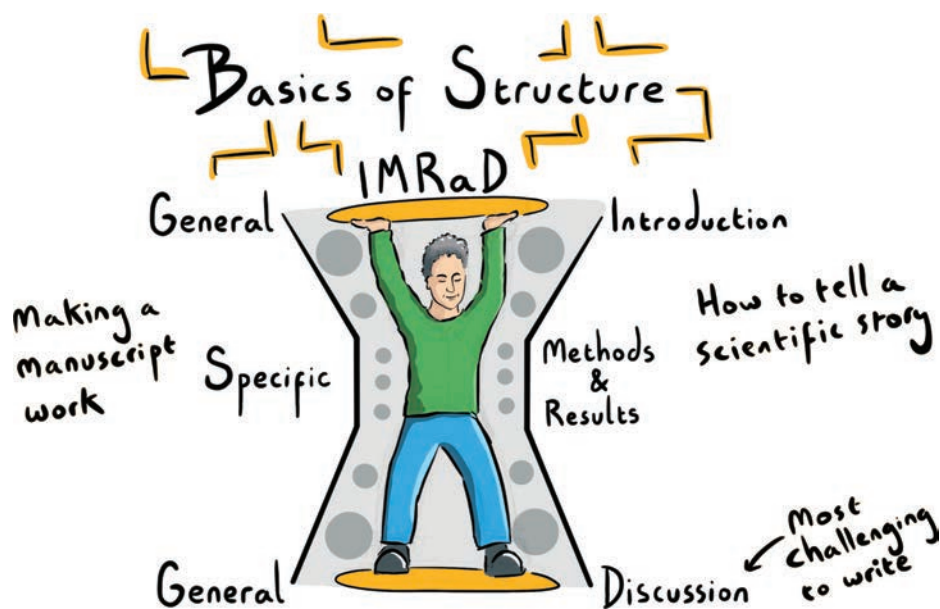


## IMRaD




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*Original research articles almost invariably follow a time-tested structure—IMRaD—Introduction, Methods, Results and Discussion. This chapter presents the structural basis of IMRaD and emphasizes the most challenging section to write—the “D.”*

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IMRaD—Introduction, Methods, Results and Discussion—is the most commonly encountered structure for telling a scientific story. The familiarity of all scientists with IMRaD facilitates communication. IMRaD *always* progresses in the logical series: past, question, present, answer, future. This chapter won’t rehash what has been so well said about IMRaD in many books and on countless Internet sites. To drive home the essence of IMRaD, I want you to do the following exercise before reading any further.

## Exercise 1

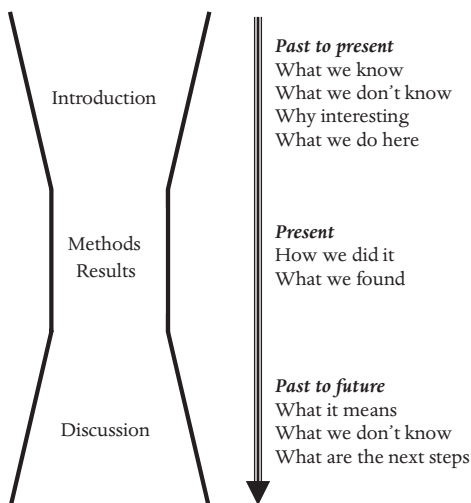
List the types of information that go into a manuscript. For example, the experimental design, statistical analysis, the conclusions. Try to be specific enough so that your list comes to 10–15 entries, and that one or more fits into each of I, M, R and D.

Now take a few minutes to think about how your own research maps onto each entry in your list and how the entries are interrelated. For example, if you indicated “experimental design” in the Methods section, then first think of the basics of your experiment, and then consider how this relates to entries in the Introduction, produces specific Results and possibly influences points in the Discussion.

The point of this exercise is to see the logical sequence of entries and their interrelations. You likely listed some or all of: I (previous study, unresolved questions, particular question of interest, hypothesis), M (methods to test hypothesis 1, 2, 3...), R (findings 1, 2, 3...), D (interpretation, relation to previous study, conclusions and future directions). It should be plain to see that IMRAD is a template for writing a study according to the scientific process.

## The hourglass

The metaphor for the IMRAD structure is an hourglass (Figure 8.1). The Introduction begins wide and general, narrowing to the specific puzzle. This narrowing doesn't change much in the Methods and Results, and finally widens in the Discussion. IMRAD basically says: this is what is out there (wide), this is what we don't know (narrowing), this is what we did (specific) and this is what it means (widening).



**Figure 8.1** Hourglass structure. The main flow is top to bottom, with later parts addressing problems posed in earlier parts.

Although there is considerable flexibility in the proportions of the hourglass, two guidelines are useful. First, the hourglass should never get too wide (generalities), the maximum usually being a few lines at the beginning of the Introduction and in the Discussion. A manuscript starts with the scientific background, leading in logical steps to a question in the final paragraphs of the Introduction. Then there is a sudden break to how the current study actually addresses the question (Methods) and what was found (Results). The Discussion explains the findings, their broader relevance and where to go in the future.

Second, the proportions in the Methods and Results sections will depend on how general and extensive the study is. Methods and Results usually have an internal substructure that gives the hourglass an undulating pattern in the middle. For example, you may have conducted laboratory experiments, statistical analyses, and computational modelling, and each of these will start with generalities (e.g., general culturing techniques), followed by more specific methods and details.

### Exercise 2

Select two articles from your *Models*. Begin reading the first, not paying too much attention to details. As you skim IMR and D, picture the width of the hourglass changing. On a separate piece of paper trace the hourglass paragraph by paragraph. Now do the same for the second article (and eventually other articles, should you have time), tracing the hourglass next to the first one. Did the hourglass shape reflect the scientific and communicative quality of each study? Your interest in each?

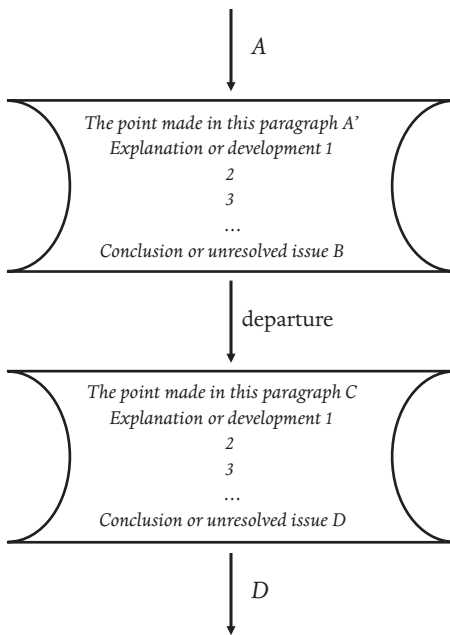
## Paragraph structure

The Introduction and Discussion are the two most challenging sections to write. Nevertheless, their paragraphs have a characteristic internal structure. Each starts with a statement of what the paragraph is about. This is followed by one or a series of developments in a logical order that can be chronological, categorical (e.g. laboratory followed by field studies) or may lead to the subject of the following paragraph. The last sentence usually “ties the knot” (e.g. summarizes, concludes, generalizes, resolves...) and/or creates a transition that will be taken up in the first sentence of the next paragraph. Similar to the overall structure of a paper, each paragraph in the Introduction and Discussion typically has an hourglass shape.

## The Introduction

An Introduction will have all of the following components<sup>1</sup>:

1. The general context.
2. What is known: review of the literature.



**Figure 8.2** Generic paragraph structures in an Introduction and Discussion (the overall logical flow is represented by subject points A–D). The first sentence (and internal development) follows from the content of the preceding paragraph (indicated by ‘), or marks a departure from the preceding paragraphs.

3. What is not known: the puzzle.
4. Why the reader should care: why the puzzle and its resolution are important.
5. What the study does: test a hypothesis or address a question.
6. The actual approach taken.

Do the following exercise that will help you learn the essential features of an effective Introduction.

### Exercise 3

Using the same *Models* from Exercise 2, carefully examine the structure of the Introduction. See how and where the authors provide general context, what is and is not known (and whether they provide detail and/or refer the reader to referenced material), lead up to a question, problem or puzzle and their hypothesis, how they articulate the interest and importance, and finally the description of the study's objectives and how these were accomplished. Make a note of the logical flow of the paragraphs and development within each paragraph as per Figure 8.2. Are some of your *Models* more effective overall or in particular parts of the Introduction? Why?

The Introduction lures the reader into a scientific question. Stimulating the reader's curiosity is so important that it needs its own (the next two) chapters. The Discussion is no less crucial and is the focus below.

## The Discussion

The Discussion is the most open-ended section in an original research article. It is an update of the Introduction, with the added challenge of interpreting the Results and presenting future directions. Discussions take on a variety of forms, both in terms of basic layout, and the fine structure.

The overall design of the Discussion can differ from journal to journal. It can be a separate section called “Discussion” or “Conclusions,” or may consist of one or more paragraphs tacked on at the end of the Results section. Some journals adhere strictly to the section name and what the section should achieve, whereas others are flexible, the only real checks coming from the views of referees and editors.

Why is the Discussion so important? After all, the Introduction has provided the background, the basic puzzle, the question being addressed and a trove of relevant literature. The Results presented the findings—the astute reader can draw her own conclusions and their relevance by referring back to the Introduction. Indeed, one *could* stop there and have learned the essentials. What the Discussion adds is relevance—something that the reader would be thinking about anyway while reading the Results, but which the authors will actually provide, and likely do so in much more depth.

### Discussion Last, But Not Quite

The Discussion is the final written section. You will probably have been contemplating it from the beginning and possibly will have taken notes as the writing of the earlier parts took form. Despite considerable latitude in writing the Discussion, it needs a plan, a foundation. Fortunately, you need not look far. The IMR is the foundation to build the D.

Think about it as follows. A scientific study has three main periods. The past up to the present (I), the present (M and R), and the past to present to future (D). Whereas the first two periods and their sections follow on from one another, the third—the Discussion—traces back to points in the Introduction, goes through the present (M and R) and projects into the future. Thus, a scientific paper is not a simple, uni-directional logical line from beginning to end. It's a loop.

A good Discussion revisits the Introduction. It puts both the general topic and specific question addressed into perspective. It provides answers and generates new questions.

### The List of Six

An effective Discussion will present the:

1. problem;
2. resolution;
3. contributions;

4. limitations;
5. conclusions;
6. implications.

#### Exercise 4

Select one of the articles from the previous exercise. Read the Discussion and note where you find each of the six above points. Think about how these structural features contribute to the effectiveness of the Discussion as a vehicle for closing the study. If the *Model* has fewer than all six points, consider how the absence of each affected your assessment.

### Writing a Discussion

Before presenting examples of the key first paragraph in a Discussion, here are some basic pointers for when you actually start writing.

First, list the six points for an effective Discussion at the top of your document and develop each in a sentence or two in the context of your study. Try to include keywords, phrases and descriptions that will enable you to return to the list and transform it into scientific prose. It is possible that you may want to downplay some of the six points.

Second, transform the points and descriptions above into an outline of the paragraphs in your Discussion. You can start with a title and a one- or two-sentence description for each paragraph. Place the paragraphs in a logical order, eventually using one of your *Models* as a guide. Note that you may have one or more paragraphs relating to each of the six points, and that some of the six will be treated in the same paragraph. You can always come back and add, delete or modify elements from this list.

Third, although there is no “one size fits all” for how to organize content, consider the following parameters: scale, importance and confidence. Scale refers to going from small to big, local to global and few to many (or the reverse). Importance answers the question “Why care?”. Confidence is the extent to which your results are robust and general.

Fourth, if in outlining your Discussion multiple themes emerge and you decide to develop each in some detail, consider establishing subsections with explicit titles. Not all journals allow this. These subsections should form a logical sequence. *Models* will be useful since this is a more advanced feature of Discussion writing.

Fifth, embark on the actual writing. Proceed in a series of “sweeps,” starting with notes and observations of what you plan to include, why, possible concerns, etc. With each sweep, you will need to populate your text with supporting references. Some of these citations will be discussed in some detail, others will serve as support for claims or statements. As you proceed, highlight parts that need more work and resolve past concerns.

Keep in mind that writing the Discussion takes time and effort, but is highly rewarding. It's where you inform the reader of why your findings are interesting and important.

## The Crucial First Paragraph

The Discussion is special—it is the only section where the first paragraph *really* matters. The first paragraph of the Introduction usually presents general context—not very important. The first paragraph of the Methods is a strictly factual recount (or overview) of what was done and how. The start of the Results is somewhat constrained to follow the logic of the scientific process, and is not arranged a posteriori from most to least significant findings. The first paragraph of the Discussion however is pivotal: it announces the interpretation of the science just presented and presages the paragraphs that follow.

So, let's look at some real examples (with cited references omitted).

### Reiterate results

We have presented and demonstrated the use of several of the more common methods for dealing with uncertainty in model parameters when designing reserve networks. These efforts have provided four key results. First, all of the approaches explicitly allow one to quantify the effects of uncertainty on model results and the consequences for subsequent decisions made in the face of uncertainty. The ability to quantify the impact of uncertainty creates flexibility in the management decision process and provides a mechanism for describing realistic outcomes. In some cases, stakeholders may be willing to take greater risks if such risk creates the potential for a larger pay-off; in other cases, stakeholders will demand that any action provide the greatest amount of certainty in results. However, under the precautionary principle these decisions should be based on worst-case scenarios. Increases in persistence probability pay the price of requiring greater certainty in key model parameters, and this tension is quantified in these uncertainty models.

Second, distance...

(*Ecology Letters*, vol. 9, pp. 8, 9)

*Comment:* This is a straightforward and powerful way to launch a Discussion. It is most effective when the study is complex, with multiple important results. This is not to say that it is a good idea to dedicate a whole paragraph to each and every significant result. Rather, the question you need to ask is whether the *first* paragraph should announce that you are about to describe your main results in more detail than in the Results section itself.

### Relevance

The series of tests we performed supported niche mechanisms as the primary drivers structuring these prairie grasslands, even though the observed species

abundance distribution at CDR was qualitatively consistent with neutral theory. These results illustrate that a distribution fitting approach could lead to incorrect assumptions of neutrality. Additionally, not only can niche and neutral models predict similar species abundance distributions, but the distinction between the relative fit of alternative predicted distributions to species abundance distributions is contentious and depends on which goodness-of-fit measurement is used. Our ZSM fit outperformed the log-normal fit in terms of  $\chi^2$ , but not  $R^2$ , which also suggests the need for better niche models that incorporate species traits such as  $R^*$  with dispersal limitation and stochasticity, and methods to distinguish between the relative importance of these processes. Fitting a neutral distribution to observed species abundance data was proposed as a means of assessing the importance of neutral processes in ecological communities; deviations from this null expectation should indicate greater relative importance of other processes. Because our observed species abundance distribution was consistent with neutrality while our stronger tests were not points out the potential limitation of using neutral distributions as a null expectation and test of neutral processes. We reassert that stronger tests are needed, including tests for relationships between abundance and ecologically relevant traits.

(*Ecology Letters*, vol. 9, pp. 19, 20)

This paragraph is amazing. It is a microcosm of the study itself and, although it reads in some respects like an Abstract, it is far more informative. The sentences and their wording are very carefully chosen to create a logical sequence of information highlights, balancing communicative quality with scientific detail. The reader almost does not need to read on, but wants to, because this lead-in sparkles.

### Context first

Over the past century, grasslands and other seminatural plant communities in temperate Europe have suffered dramatic decline in their area due to land-use changes, and thereby once widespread vegetation types have become highly vulnerable. But what we have lost in area we may still have in species richness. Many grassland plant species with long life cycles, slow intrinsic dynamics and relatively large populations appear to occur as remnant populations and communities in modern landscapes. Given the biological traits of the species, it may take a substantial length of time before the adverse consequences of habitat loss and fragmentation become apparent in terms of greatly reduced local and regional species richnesses.

Our results strongly support the notion of remnant grassland plant communities with a slow response to environmental change...

(*Ecology Letters*, vol. 9, pp. 74, 75)

This is a highly effective first paragraph, taking the tack that the scientific problem is important and speaks for itself. But presenting context alone in a first



paragraph has its risks, since the writer may get bogged down in the details of recontextualizing the Introduction. To make this Discussion take off, the authors create the effective “rupture”: the contrast between what appears to be an almost insurmountable problem (“... it may take a substantial length of time before the adverse consequences of habitat loss and fragmentation become apparent...”) and the reporting of an interesting finding at the beginning of the second paragraph. This device is similar to the “hook” used in the Abstract and Introduction, and described in Chapters 9 and 10.

### Strong, short statement

Our sample of species included trees belonging to different evolutionary phyla (conifers vs. broadleaves), with different water transport characteristics (ring porous, diffuse porous and tracheid bearing), leaf ecology (evergreen vs. deciduous) and intensity of management practices (native unmanaged stands vs. intensively managed plantations of introduced species). Because of this wide variability, the consistency of our results suggests a degree of generality and may reflect the overall effects of ‘extrinsic’ factors such as plant size on water and carbon relations.

(*Ecology Letters*, vol 8, p. 1186)

This is a clever and highly effective first paragraph. The authors employ three devices. First, the paragraph is short and to the point—only 79 words. Second, the first two-thirds of this paragraph relates the robustness and generality of the study. Third, although avoiding detail (which will come in later paragraphs), the authors clinch the paragraph with the main result in less than 10 words.

The above examples of effective first paragraphs are representative of the different strategies you may use in beginning to cast this important section. In general, avoid taking a passive tone, rehashing a multitude of details and over-emphasizing limitations. This goes for the first paragraph and indeed the Discussion as a whole.

Just to drive these messages home, below I give a reworded example of a first paragraph, based on an actual manuscript rejected (for a variety of reasons) from *Ecology Letters*. The Discussion began:

Figure 8 showed  $Z0/Z1 < 6$  for most species, suggesting that Minit was close to or above Mopt. X did not follow this rule with  $Z0/Z1 > 6$ ...

Would anyone want to read further?

Although there is no right or wrong choice in structuring the first paragraph of the Discussion, the launch you choose will influence the tone and logical progression for the remainder of this section. Because of the importance of the lead paragraph, it is a

good idea to write first drafts of two or more versions, and to outline logical follow-on paragraphs for each alternative. Compare these and decide which is the most effective communicator.

## The ending

Like any good story, a scientific article will have a purposeful ending. The ending may be one or a few sentences, a paragraph, a dedicated subsection or a full section (e.g. Concluding remarks).

Endings have many purposes, including:

- tying up loose ends;
- reiterating the main findings;
- presenting greater relevance;
- paths for future work;
- guarded speculations;
- limitations and their potential resolution.

The article's ending affects the reader. It metaphorically talks to the reader on the mountain peak: reviewing the climb, how it could have been better accomplished, what is its greater significance and future climbs in store.