

# Writing smart: Writing quality research papers

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## 3.1 Introduction

Victor Hugo, the author of *Les Miserables*, was in the United States when the book appeared in print. He wired his agent in Paris, “?”. The agent wired back “!”; it was selling well. A book is not complete until it has been read and interpreted: it is a process that includes its readers. A film also must be seen and interpreted; it is a process that includes its audience.

Likewise, doing science goes beyond the act of discovery, recording of data, and its interpretation by the author to include the act of interpretation by the reader. A scientific document is also a process; it is incomplete without its interpretation by its reader. Hence, the scientific document must be written well.

There is another reason for writing well. In science, the credit for a discovery goes to the person who first convinces the world, not necessarily to the person who first makes the discovery.

The difficulty faced (by many) in reading a large fraction of the scientific literature is not, as is generally perceived, due to the complexity of scientific concepts, but is due to these difficult-to-read documents being poorly written. Scientific documents, however, need not be difficult to read, or even to write. In the rest of this article, we attempt to provide some insight into what goes into writing well. In doing so, we rely heavily on our own experience as authors, as reviewers, and as editors, on what we have, consciously or unconsciously, learnt from others (in particular from reading well-written papers, reviews, and replies to reviews), and on the considerable literature now available on *scientific writing* in print and on the Internet.

We assume that you, our readers, have written college laboratory reports. These reports typically discuss one experiment, whereas a research paper typically reports the results of several experiments, which together constitute one experiment ensemble that can form a coherent “investigation”. The college laboratory report is also confined to describing an experiment whose results are well known (all such experiments have always been done before), but a research paper reports new data or hypotheses. Going beyond the few sentences that the college student is comfortable writing makes it essential to pay attention to structure (of the document and its units), to the organisation of ideas and material, and to writing style. A research paper also goes through an established process of peer review before it appears in print; this makes the review process an integral part of the process that is a research paper. In this article, we often use the analogy to the familiar territory of a laboratory report to make a point.

This article is organised as follows. Section 3.2 presents key structural principles, Section 3.3 deals with order and organisation, Section 3.4 deals with style, Section 3.5 gives a brief overview of the peer-review process, and Section 3.6 takes a brief look at modern tools that are now indispensable for writing a research paper. Section 3.7 concludes the article.

## 3.2 Structural principles

Since the purpose of a research paper (the ideas in this section apply to all of scientific writing) is to communicate, not merely present, data or ideas, it is essential for an author to understand how a

reader goes about reading, to know his audience. Such an understanding, implicit in the good writing of all times, has recently become more established through research in the fields of rhetoric, linguistics, and cognitive psychology. (This section is based on an article by George Gopen and Judith Swan [1]. Titled *The science of scientific writing*, it first appeared in *American Scientist* in 1990, but is now accessible on the Internet. It is one of the articles listed on searching Google for *scientific writing*. Since the elements of this section are based almost exclusively on this article, we do not cite it formally in order to save space. Verbatim quotations appear, however, in double quotes.)

### 3.2.1 Reader expectations

“Readers do not simply read: they interpret.” Hence, a research paper, or any unit of the paper (even its smallest functional unit, the sentence), is subject to interpretation by the readers, who are likely to interpret it in different ways. “The methodology of reader expectations is based on the recognition that readers make many of their most interpretative decisions about the substance of prose based on clues they receive from its structure.”

To see the interplay between substance (of the paper or its unit) and structure, consider the following example. Suppose we measure the temperature of a body every three minutes for 15 minutes. “These data could be presented by a number of written structures.” Consider two of them [1].

t(time, min)=0, T(temperature, °C)=25; t=3, T=27; t=6, T=29; t=9, T=31; t=12, T=32; t=15, T=32.

time (min)	temperature(°C)
0	25
3	27
6	29
9	31
12	32
15	32

Though the same information is presented in both formats, most readers find it easier to interpret the second. Though familiarity with the tabular format may be one reason for this, more significant is the structure of the second table, which “provides the reader with an easily perceived context (time) in which the significant piece of information (temperature) can be interpreted”. The context on the left produces “an expectation of regularity”; “the interesting results appear on the right in a less obvious pattern, the discovery of which is the point of the table.”

Reversing the two columns makes the table much harder to read. Since we read from left to right, we prefer the context, the familiar element, on the left, and the new, intriguing information on the right. Therefore, “information is interpreted more easily and more uniformly if it is placed where most readers expect to find it”. These needs and expectations go beyond tables and figures to affect the interpretation of the text. The location of information in the paper matters, and authors can exercise a better control of the process of interpretation if they are aware of these reader expectations. Repeated violation of these structural principles forces readers to expend their energy on deciphering the paper and the author's intent, instead of expending it on evaluating the merits of the paper.

### 3.2.2 Unit of discourse

One reader expectation concerns the unit of discourse, which could be a sentence, a paragraph, or a

section. “Each unit of discourse, no matter what the size, is expected to serve a single function, to make a single point.” An analogy with computer programmes may help understand this better. Large programmes are typically broken into smaller parts, called *functions*. The very name indicates the purpose: the task of a function is to compute one complete element or part, and it is distinguished from other functions by what it computes and what it does not compute.

These reader expectations cover the entire paper, from its largest units (sections) to its smallest (sentences, or clauses in a sentence). We examine the smaller units in the rest of this section.

### 3.2.3 The subject and its verb

Consider the following sentence. 'The greatest Italian navigator, who was funded by Queen Isabella of Spain to sail west from Europe to discover a new route to the east but ended up on the American continent in the late fifteenth century to set in motion a great wave of migration from Europe, was Christopher Columbus.' This sentence is difficult to read, but the difficulty does not stem from its length. The problem with the sentence is that its grammatical subject (the greatest Italian navigator) is separated from its verb (was) by 44 words that form an adjective clause describing the subject. “Readers expect a subject to be followed immediately by the verb.” Until the arrival of the verb, the purpose of the subject and the sentence remains unclear. The reader therefore resists interpreting anything in the interrupting clause as being important. Here, the interrupting clause provides important information, but it is lost on the reader who waits for the verb. The problem lies with the structural position of the clause. Rephrasing the sentence, even without splitting it into two sentences, helps the reader. 'The greatest Italian navigator was Christopher Columbus; he was funded by Queen Isabella of Spain to sail west from Europe to discover a new route to the east, but ended up on the American continent in the late fifteenth century to set in motion a great wave of migration from Europe.'

### 3.2.4 The stress position

All the possible positions in a sentence are not equal; the end of the sentence, called the *stress position*, is a more appropriate place for the material to be emphasised because it is there that readers naturally expect to find the emphatic part. The psychological reason for this is that “we tend to take something like a 'mental breath' as we begin to read each new sentence, thereby summoning the tension with which we pay attention to the unfolding of the syntax”. As we find the sentence nearing its conclusion, we exhale this mental breath, producing a sense of emphasis.

We also like being rewarded for our labours, and finding the exciting, emphatic material at the end of a sentence is rewarding. Beginning instead with the exciting material and ending with a “lack of lustre” is disappointing and “destroys our sense of momentum”. In other words, “save the best for the last”. (Note that television serials also exploit this 'stress position' to retain their audience for the next episode.) In the following example (adapted from [2]), the first sentence places emphasis on the 'middle of the valley', the second on 'the winding stream'. 'The winding stream flowed through the middle of the valley.' 'Through the middle of the valley flowed the winding stream.' The appropriateness of the choice depends on what the author seeks to emphasise.

“The stress position is a moment of syntactic closure.” When a reader reaches its beginning, there is nothing left in the sentence or clause but the material being presented. The size of the stress position is not fixed: it may be a single word, or may extend to several lines, as in a list. “A sentence is too long when it has more viable candidates for stress positions than there are stress positions available.” Within a sentence, secondary stress positions can be created by using colons and semicolons, as in the example in Section 3.2.3. Thus, it is not the length of the sentence that matters, but the effective use of stress positions to create and transfer emphasis.

### 3.2.5 The topic position

Like the left column of the table in Section 3.2.1, the beginning of the sentence is the place for the familiar element, for the old information, which links backward to the previous discussion and provides the context for the new information to follow. This beginning position is called the *topic position*. It provides the reader with the perspective and context for deciphering the sentence as a unit: “Readers expect a unit of discourse to be a story about whoever shows up first.” In the sentence about the stream (Section 3.2.4), the first form tells us about the winding stream, the second about the middle of the valley.

“When the new information is important enough to receive emphasis, it functions best in the stress position.” Therefore, “put in the topic position the old information that links backward; put in the stress position the new information you want the reader to emphasise.” When the old information does not appear in a sentence (or in a larger unit), the reader is forced to find the thread of the discussion by attempting to connect backward. Providing this connectivity is the responsibility of the author, but is often missed when the connections are 'obvious' to him. The connections then become implicit; it is necessary to make them explicit to avoid possible logical gaps. (Note that television serials exploit the 'topic position' too: they typically begin with a 'recap' of the previous episode, providing the viewer with the 'backward connection'.)

### 3.2.6 Articulation of action

Since the topic position decides whose story is being told, it is essential to maintain the story's focus. If the element in the topic position changes in every sentence, it makes for difficult reading. A key culprit in such cases is often the verb. Frequent use of passive verbs (is, are, was, were, has, have, had) makes it difficult to locate the action in a clause or sentence. “Readers expect the action of a sentence to be articulated by the verb.”

The structural principles articulated above for the smallest functional unit, the clause or the sentence, apply equally well to the paper itself. Each of the larger units, paragraphs or sections, is expected to lead the reader from the known to the unknown in a series of logical steps. Hence, just as the position of words in a sentence is critical, so is the order of the paragraphs and sections within the paper.

## 3.3 Order and organisation

A research paper is expected to tell a coherent story from beginning to end [3]. In this sense, it is similar to editing films (or telling stories); in editing films, a series of frames, shot at different times and in different locales, is arranged to form a logical sequence, to tell a story. Likewise, a research paper tells the story of an ensemble of experiments that form an investigation, the order in which the experiments were performed often being different from the order in which they need to be presented to ensure smooth flow from old to new information. Hence, research papers must follow some order.

The organisation of a typical research paper is not significantly different from that of the college laboratory report. In general, the typical research paper has an abstract, an introduction, a section on the materials and methods used in the investigation, a section on the results of the investigation, and a section discussing these results and their novelty. Though the number of sections may vary depending on the length and nature of the paper and on the complexity of the experiments, the sections, no matter what their names, follow the above order. Hence, we briefly state the function of each section of the paper.

### **3.3.1 Abstract**

An abstract is a concise summary of the paper. It is usually restricted to 250 words in most journals because it is used by literature databases and indexes (like PubMed, Chemical Abstracts, etc.). Hence, it should be limited to stating the problem and the solution. Since many readers use the abstract to judge if they wish to read the entire paper, it is essential that they be able to determine from it the relevance of the paper to their work.

An abstract is expected to state (i) the objective of the investigation (the 'why'), (ii) the intent or the methodology in brief (the 'how'), (iii) the results of the investigation in brief (the 'what'), and (iv) the significance of the results and the conclusions (the answer to 'so what?') [3]. It should not give any information that is not contained in the paper and should not, in general, cite any references (because these will not be included in the databases that use the abstract). A well-written abstract also contains keywords that can lead a potential reader to the paper [4].

### **3.3.2 Introduction**

The introduction is expected to provide the rationale for the investigation, for the 'central experimental question'. It is also expected to provide the relevant background for the investigation in the earlier literature, thereby providing the reader with the context in which to place the paper, and to provide a justification, if required, for the choice of method used in preference to other methods. The last paragraph is expected to summarise the main conclusion. Stating explicitly the hypothesis to be tested and the conclusion is good [3]: suspense and climax do not belong to the research-paper genre.

A well-written introduction does not ramble; it keeps the focus on the problem, and leads the readers to the hypothesis to be tested in the paper [4]. This is especially critical in presenting the background information, in which it is essential to choose carefully the references to ensure that it is the salient background, not an exhaustive review, that is presented. In particular, avoid listing references serially: "X did this. Y did this. Z did that." The author is expected to provide a coherent summary of the earlier work, grouping these papers as required. Else, what the reader is left with is but a list of references and an expanded title, not the insight (into the earlier results) that he needs to interpret the paper.

### **3.3.3 Materials and methods**

A brief statement on the methodology to be adopted is included in the introduction. The section on materials and methods expands on this by providing details. The technical description should be precise but detailed enough to enable a reader to follow the experiments and repeat them. Though many, maybe even most, readers will skip this section, it is essential to write it carefully because repeatability is the bedrock of the scientific method. It is the material in this section that allows a reader to repeat your experiments, and it is bound to be read carefully by a (good) reviewer. If it does not stand the test of his scrutiny, if he cannot assure himself that he can repeat your experiments, the manuscript runs the risk of rejection [5].

This is also the first section that may have subsections. The subsection headings should match those in the section on results; this will allow a reader to see easily the connection between an experiment and its results, providing a logical structure to these two units. It is also essential to ensure that a description of the results does not creep into this section; the two are best kept separate, enabling a reader to judge the merits of the methodology independent of the results.

An appropriate citation should be given for the methods or statistical techniques used only if they

are new, or are likely to be new for the majority of the readers expected to read the paper. If the methods are new (unpublished), they should be described in detail. Standard methods and statistical techniques should be used without comment [5].

This section usually contains more technical terms than the other sections, making it more likely that a copy editor will miss misspelled words in the last stage of the publication process; this, and that spell-checkers may not be aware of technical words, necessitates careful reading of the proofs.

### **3.3.4 Results**

Unless the paper is presenting a new method, it is in this section that the author gets the opportunity to present his new findings. This section should begin with a statement of its rationale or objective and an overall view — the big picture — of the methods used [5]. Then it should present the results of the investigation.

In presenting the results, avoid a direct transfer from the laboratory notebook or experimental log to the paper. It is the representative data, not all the data, that need to be presented. It is essential to discriminate, so that the reader is presented with what is essential for him to interpret the paper; this task of ferreting out the essential results from a maze of data should not be left to the reader. If an author does not discriminate between the important and trivial results, it shows that he himself does not understand the significance of the investigation. Hence, the temptation to show all the results of all the experiments should be avoided. Also to be avoided is redundancy: do not repeat in the text what is obvious in tables or figures.

### **3.3.5 Discussion**

The discussion should highlight the conclusions and draw attention to the novelty of the paper. As in the other sections, brevity is important here too. A long-winded and meandering discussion, or one that makes claims that are not supported by the results, obscures the findings of the paper, making it tempting for a reviewer to recommend rejection.

It is the principles that can be inferred from the results, the relationships among the variables that can be inferred from the results, and the generalisations that can be deduced from the results that form the key elements of this section. Discuss the results; avoid repeating them. This is also the place to make comparisons with other published papers, and to show the similarities and contrasts between them; it is the place to discuss possible theoretical implications or practical applications or consequences of the paper and its findings; and it is the place for any reasonable speculation, for defining points not settled by the investigation reported in the paper.

The discussion is also the section that presents the significance of the paper. Where does the paper stand in the crowded marketplace that today's scientific world resembles?

### **3.3.6 The title**

Choosing an appropriate title is important because more people read titles than read papers; it is often the title that decides if a prospective reader goes further. Titles are part of all abstracting and indexing services. Hence, it helps to ask yourself how you would look for such information (as contained in the paper) in an index [5]; this will help decide the words that the title must contain. Decide who the likely readers are, and the (key) words that need appear in the title usually will be easier to find.

Titles should also be free of abbreviations, chemical formulas, and, to the extent possible, jargon. A

title should not be too short because such a title is unlikely to tell a reader what the paper contains. It should also not be so long that it reads like an abstract. Avoid titles like “Some studies on ...” because titles must be specific in order to be informative. Use of such vague phrases also adds to the length of the title.

The title is like a label for the paper; it is not a sentence [5]. Hence, the usual order of words does not hold for a title, but the order of words is even more important because misplaced words in a title can be hopelessly misleading (if not absurd), as seen from this example [5]: “Mechanism of suppression of nontransmissible pneumonia in mice induced by Newcastle disease virus”. Day [5] defines a good title as one that describes the contents of the paper in the fewest possible words, making it imperative to choose with care every word in the title. Note that two conditions need to be fulfilled: the title should tell a reader what the paper is about, and it should do this in as few words as is possible.

### 3.3.7 References

Science progresses by building on existing work, and it is established tradition to cite the earlier literature that a paper builds and relies on. These citations are collected in a reference list, the format of which, like the format of the citation in the text, depends on the journal.

## 3.4 A matter of style

A research paper is not the place for literary flourishes; it is clarity and strict adherence to facts that distinguish it from other literature. Nevertheless, writing style does matter even in a research paper. Just as the structure of the paper and its constituent units is critical, so is respect for the basic rules of grammar and usage. Since the basic goal of a scientific investigation cannot be accomplished until it is published in a peer-reviewed journal, neglecting language skills can cost a prospective scientist dearly in his career. A discussion of the rules of English grammar is beyond the scope of this article (and these rules are dealt with in several admirable books, some of which are listed in the bibliography); what we present are three general principles that apply to a research paper and some practical steps that improve writing style.

### 3.4.1 Clarity

The first principle is clarity: scientific terminology carries precise meaning and must be used with care. Though a research paper is expected to contain technical terms, it is essential to avoid sinking in a cesspool of jargon. Do not use jargon to cover the lack of material; such a manuscript is unlikely to get past a good reviewer.

Be explicit; do not leave it to the reader to derive your implicit conclusions. Put statements in positive form, using *not* in denial or in antithesis, not as a means of evasion [2]; for example, prefer 'dishonest' to 'not honest' and 'trifling' to 'not important'. Apart from saving a word, the positive form is more satisfying and concrete. Use definite, specific, concrete language in preference to the abstract; for example, 'rained every day' is better and more expressive than 'unfavourable weather' [2]. Writing plainly, preferring simple words to wordy words is a key to achieving clarity; hence, plain writing was encouraged even as early as the 17<sup>th</sup> century, when the Royal Society conceived the modern scientific journal [6].

### 3.4.2 Brevity

The second principle is brevity: Be concise because vigorous, honest writing is concise. Omit

needless words. “A sentence should contain no unnecessary words, a paragraph no unnecessary sentences, for the same reason that a drawing should have no unnecessary lines and a machine no unnecessary parts” [2]. Use of the active voice, minimal use of passive verbs (is, are, was, were, has, have, had), adherence to the structural principles outlined in Section 3.2, and careful organisation of the paper help in achieving conciseness.

### 3.4.3 Tense

The third principle concerns the tense used for sentences; this depends on the material they contain. Use (i) present tense to state a previously published result that is accepted as fact, (ii) past tense to report your methods and results (because they are not yet accepted facts), (iii) past tense to attribute actions or findings, (iv) past perfect tense (had been) to indicate action that happened before other past action, (v) present perfect (have) to indicate an action recently completed or continuing to the present, and (vi) present tense to refer to other parts of the paper.

### 3.4.4 Tables and figures

A research paper makes considerable use of tables and figures to present data. Hence, the elements of style extend to include them. It is in the section on results that a choice often has to be made between presentation of data in text, in tables, or in figures. The appropriateness of the choice depends on the volume and character of the data. If the data are few, say just two numbers, then they are best presented in the text. Else, the choice lies between a table and a figure. The choice between these two options often depends on the volume of the data and on whether they show a trend [5]. For example, the temperature data tabulated in Section 3.2.1 are better tabulated if the number of data points is small; if the data, however, show a trend, as they do in the values listed (the temperature seems to stabilise at 32 °C), a figure (line-plot or graph) is better because the reader can visualise the behaviour and draw inferences immediately.

When tabulating data, ensure (see Section 3.2.1) that the tabular material reads down, not across. The caption of the table describes the table, just as the title of the paper describes the paper; hence, keep it short. Additional material is usually included by most journals in explanatory footnotes and should not be mixed with the caption.

Figures need to be prepared carefully. Avoid both extremes: do not clutter a graph with more lines than can be interpreted with ease, and avoid presenting similar data in separate graphs. Just as a sentence should have no unnecessary words, a paper should have no unnecessary figures. Presenting each graph separately, apart from violating the principle of brevity, forces a reader to make the effort to infer the connections between the different variables plotted.

A good rule is to prepare figures to the size required by the journal; decide if you want a figure to appear in one column or be spread over two columns, and prepare it accordingly. An obvious advantage of doing this is that it helps reduce the work to be done when revising the manuscript or communicating the final version to the publishing office of the journal. A more subtle advantage, however, is that the reviewers (and the editor) see exactly what the reader will see in the printed journal, making it possible for them to spot potential difficulties that a reader may face in interpreting the figures. Preparing figures initially to the expected final size also avoids the need for the publisher to enlarge or reduce the figure to fit the journal requirements, thereby maintaining the original quality. Given the quality of modern laser printers and the relative ease, compared to even a few years ago, of obtaining laser printouts of figures, providing the publisher with camera-ready figures or electronic copies ensures better figures in print.

Most publishers now require figures in one of two electronic formats, PostScript or Encapsulated



PostScript, because these are vector formats in which lines are not smudged, unlike in raster formats like GIF or TIFF or in comparatively more compact but lossy formats like JPEG. Even if the publishers are willing to accept GIFs or TIFFs or JPEGs, it is better to send them the figures in a vector format; an exception may, however, be made in the case of photographs or satellite images. If the figures are photographs, mark the top of the figure on the reverse with a soft pencil; the onus of the figure appearing the right way in print rests with the author, and careful work in preparing the original manuscript helps when revising the manuscript or communicating the final version.

### 3.4.5 Crossing borders

Interdisciplinary papers are becoming common as science is applied to solve or tackle complex, real-life problems. Since proposals based on interdisciplinary programs are more likely to attract funding these days, papers that result from these programs are becoming more common and are being published in journals whose scope cuts across the well-defined but porous borders of the traditional disciplines. How do the principles of writing apply in such cases when the paper addresses an audience that crosses these borders?

The principles remain intact; it is just that the audience changes, and the author (or a group of authors cutting across these borders) addresses a more varied audience. If the paper is short, say a note, then do not include more material than is needed by any section of the audience to appreciate the paper's contents. Longer papers may, however, need to present a little more detail, in particular of the background of the problem and of the methods used, to enable a diverse audience to follow the paper. Do not, however, make the mistake of adding to the length of the paper by attempting to add material to cater to the diverse audience; the length of the paper should be determined by its basic contents and by the journal to which it is being submitted.

Irrespective of the kind of paper, it is essential to 'know the audience'.

### 3.4.6 Steps to writing better

Following some well-defined steps help bring discipline to the process of writing, and some of this discipline or order is transferred to the paper itself. There are four steps to writing [7].

- First, plan the paper. Organise your thoughts and prepare an outline. This gives the paper a skeleton that you can flesh as you expand the outline.
- Second, write the first draft using the outline. Avoid interruptions in the process of thought; do not revise as you write, for this intrudes onto the thought process and breaks its flow. “Writing and revising are different activities that are best performed separately” [7]. Do not attempt the near-impossible task: a polished final paper in the first draft.
- Third, keep the draft aside and allow some time for your mind to become capable of taking an objective view of the draft. Trying to revise the draft immediately after finishing it often is difficult because the thought process that produced the draft simply repeats, making the draft appear perfect and revision difficult.
- Fourth, revise the draft. “Successful writers not only revise, they revise assiduously and interminably” [7]. In revising, go over the paper five times, expending energy each time on a different objective.
  - The first revision should be limited to the paper's contents. In particular, answer two questions [7]. (1) “Does the paper contain all that my readers need?” (2) “How

much material can I remove without interfering with my readers' understanding and needs?" Answering both questions requires that you know your readers and understand their expectations.

- Strive for clarity in the second revision.
- Correct your writing (for grammar and diction) in the third revision. Depending on your writing skills, this may involve several rounds of re-writing. The number of times you go over this step of revision will decrease as good writing becomes more natural over time.
- Brevity is the objective of the fourth revision. Eliminate all unnecessary words that you can identify. As with the third step, you will find fewer superfluous words to eliminate as your writing improves.
- The fifth revision is for improving the style. In many cases, authors stop after the fourth revision, and often this is sufficient to produce a good paper. Some, however, "will be driven by pride in themselves and their work to revise thoroughly all papers that might affect their reputation" [7]. Ensure that the sections connect well to form the paper, that the paragraphs connect well to form the sections, and that the sentences connect well to form the paragraphs. In other words, ensure that the structural principles based on reader expectations are followed in the paper.

It may seem that revising a paper five times is too much effort to expend on a single paper, but the effort will pay off in due course because each subsequent paper will require less time as the principles of writing and grammar percolate into the subconscious. This step-by-step approach to writing will also save you considerable time because a research paper, unlike much of other literature, has to pass through a critical process before appearing in print.

### **3.5 The editorial and review process**

Science is not about sensationalism. Even sensational discoveries have to be reported as plain facts and the scientific community has to be convinced of their validity before they can be accepted as facts, whether sensational or mundane. The process of peer-review, in which a manuscript submitted for publication in a journal is reviewed for its scientific content and presentation before publication, exists to ensure the credibility of scientific literature. It is this process of peer-review that makes journal publications superior by far to conference publications because the latter, in general, are not subject to a rigorous review process. Hence, scientists are expected to turn their conference presentations, which often report preliminary results, into journal publications. The process of peer review also increases the pace of scientific progress by filtering 'bad science' out of the published literature. If it were not for this process, which may seem cumbersome to novice authors struggling to revise manuscripts, poorly done research and poorly written papers would soon swamp the world of science and rub shoulders with good research and well-written papers, retarding the progress of science.

#### **3.5.1 The peer-review process**

When a manuscript arrives at an editorial office, the editor first decides if the manuscript is within the scope of the journal. If it is not, the manuscript is returned to the author, and this decision can rarely be challenged because the editor has the responsibility of defining the journal's scope. The second decision concerns the format in which the manuscript has been submitted; if it is in the

format required by the journal (and many journals decide this electronically these days), the manuscript is ready for review.

Peer-reviewers are invariably scientists knowledgeable in the field. To remove the possibility of bias, most manuscripts are reviewed by three independent reviewers. Journal editors usually rely on the reviewers to make a decision regarding the manuscript, and expect them to do a fair job. The editor's choice generally rests between three options: 'accept', 'modify', or 'reject'. In a good journal, this decision is usually reached within eight weeks of receipt of the manuscript.

Manuscripts are rarely accepted as submitted. It is more likely that the corresponding author will receive a letter from the editor along with the reviews, and he will be asked to modify the manuscript in accordance with the suggestions or comments of the reviewers. The author has to decide if the suggestions are acceptable to him. If the suggested changes are minor, it is best to make the changes. If major revision is requested, the suggestions can be of two types. First, there may be lacunae in your manuscript, and these have to be addressed in the revised version. Second, the reviewer may have erred in his interpretation; in this case, it is necessary to point this out *politely* to the reviewer in your point-by-point reply. Note that the reply to the reviewers is not an arena for conflict: the review process takes cognisance of the possibility that reviewers, like authors, can also make mistakes, and the peer-review process allows the author the right to respond. The decision, as before, will be made by the editor. The other option, in the event of erroneous criticism, is to withdraw the manuscript and submit it to another journal; the first course, however, usually is the best.

The third possibility is that the manuscript is rejected. Note that most good journals reject over half the papers they receive, and that not all rejected manuscripts are unpublishable. If the data or methods are seriously flawed, many editors reject the manuscript, but would be willing to consider it on its re-submission if the flaws have been eliminated. Once again, if the flaws noted are serious, there exists the option of modifying the manuscript and submitting it to another journal. Note that it is essential to consider dispassionately the reject letter and the comments of the reviewers because submitting the flawed manuscript without modification to another journal is likely to invite another reject letter. Else, it is likely that you have succeeded in publishing a bad paper. In the long run, such success proves expensive.

### **3.5.2 Framing the point-by-point reply**

The way you reply to the comments of the reviewers is as important as the way you modify the manuscript in accordance with their and the editor's suggestions. It is essential that the point-by-point reply be framed scientifically and that it be polite. This will help both, the editor and the reviewers, to judge if the revised manuscript is acceptable. Whether dealing with a 'modify' or a 'reject', it is important to remember that the editor is a middleman between you and the reviewers. If you deal with the editor and the reviewers respectfully, and if you can defend your work scientifically, most of your 'modifies' and even your 'rejects' will in time become published papers. The editors and the reviewers are usually on your side. Their prime function is to help you publish good science. It is to your advantage to cooperate with them [5]. This also extends to nasty reviewers (at least you feel the reviewer is nasty); a polite reply to such a reviewer will work better with the editor (and very likely with the reviewer too).

We now consider the point-by-point reply. In framing this reply, reply to each reviewer's comments separately and remember to include the reviewer's comments in the reply. The reply should be framed as follows.

*Comment 1:* [Text of comment 1 from reviewer 1.]

*Reply 1:* [Text of your reply.]

*Comment 2:* [Text of comment 2 from reviewer 1.]

*Reply 2:* [Text of your reply.]

This helps the reviewer and the editor because they do not have to look at another sheet for the comments. Avoid statements like 'corrected' or 'necessary corrections have been made'. Instead, state clearly, but briefly, what you have done in response to the comments. Give a brief description of the changes made in response to the comment, and give the reviewers and editor a pointer to the changes in the revised manuscript, just as a (good) reviewer gives a pointer to the statements he finds problematic (page *a*, para *b*, line *c*).

Remember that the editor and reviewers are there to help you, and any assistance that you provide them in the review process will be appreciated. They are also unpaid volunteers, and it is unwise to waste their time.

### **3.5.3 Guidelines for editors, reviewers, and authors**

Over the years, many publishers, especially those connected to professional societies, have framed guidelines for editors, reviewers, and authors, all of whom participate in the peer-review process that forms the bedrock of science. The following discussion is based on the guidelines framed by the *American Geophysical Union* [8].

The chief obligation of an editor is to give unbiased consideration to a manuscript, and to process manuscripts promptly. He has complete authority to accept or reject a manuscript, but usually confers with associate editors or reviewers to arrive at a decision. He is also obliged to ensure that due care is taken when he has a conflict of interest with the author; in such cases, the editor delegates the responsibility to an associate editor.

Every publishing scientist is obliged to review manuscripts, and to do so within a reasonable period. The reviewer has to be on guard for potential conflicts of interest with the author; this is critical because reviewers are usually experts in the same field as the author, and may, at times, be competitors. Just as the author is expected to write logically, a reviewer is expected to review logically and provide the editor with sound scientific arguments to judge the merits of a manuscript. He is also a bulwark against plagiarism. Use of others' words, phrases, and images without proper citation violates scientific ethics and constitutes plagiarism; though the author is expected to avoid plagiarism to maintain the integrity of the scientific method, it is the responsibility of the reviewer to alert the editor to any failure of the authors to cite relevant work by other scientists. Any substantial similarity between the manuscript under review and any other published paper or a manuscript submitted concurrently to another journal should be brought to the attention of the editor.

The author's main responsibility is to present a concise, accurate account of the investigation and an objective discussion of its significance. A well-written manuscript is expected to contain sufficient detail to permit others to repeat the experiment. The author, as a member of the scientific community, has to be committed to the integrity of the peer-review process, and should avoid using material from others' work without due citation. This also extends to avoiding dual publication: the author should refrain from reporting the same research in more than one journal. He is also expected to refrain from making changes in an accepted manuscript and to inform the editor if any such changes are imperative. The corresponding author is also responsible for ensuring that only those who have contributed significantly to the research are listed as authors, and that all the co-authors have seen the final version of the manuscript and have agreed to its submission for publication.

### 3.6 Modern tools

Technological advancement has changed not only the way science is done, but also the way it is presented and evaluated. Typewriters have given way to computers, and single-side printing is being replaced by double-side printing to save paper as high-quality laser printouts become more common and affordable. We take a brief look at some of these tools.

One major task in the publishing process used to be the need to ensure correct spelling and grammar. The switch from typewriters to high-speed computers and the easy availability of good word (or text) processors have made it possible for the burden to be shifted to the author. It is the author's responsibility to ensure that his manuscript has passed through a spell-checker before it is submitted. Though copy-editors of several journals still check for spelling errors when editing the accepted manuscript, this is likely to receive less attention than grammatical errors. Some journals are almost completely electronic now, and this implies that the responsibility for the correctness of language rests almost exclusively with the author; the manuscript may pass through the peer-review process, but few reviewers will take the time to correct a manuscript's faulty language. As journals try to speed the review process to shorten the time between submission and publication, much of the responsibility for presentation will be passed on to authors, with the implication that poorly written manuscripts, or manuscripts with several spelling or grammatical errors, are either rejected or attract fewer readers. An author therefore has to ensure that his software is good and that he knows how to use it effectively. Modern word processors also provide a warning on detecting a possible flaw in grammar; ignore these warnings only if you are certain that you are correct. Indian authors would also do well to remember that most software use American English as the default; stick to it if you are submitting your manuscript to an American journal, but use British English otherwise. To give but one example, remember that the correct Indian or British spelling is *splendour*, not *splendor*, no matter what the advertisers think.

Another significant advance that computers bring to the presentation of science is in searching databases for earlier work on a subject. The earlier method was to look through the reference list of a recent paper, then work backwards through these references. Modern databases like PubMed, Chemical Abstracts, etc., the high-speed desktop computer, and the Internet make it easier to locate earlier work through keywords, and it is imperative that those looking forward to a career in science learn to use effectively these search tools. This helps avoid unwitting repetition of earlier work without proper citation, and also helps gain a better perspective of his field. It is even possible to search through 'search engines' like Google to locate authors of these papers and thereby to obtain reprints of papers that may not be accessible in your institution. In India, some libraries are designated as national centres for information in their fields of specialisation. These libraries are obliged to provide assistance to authors requiring reprints, and usually do a good job; learning how to use these services effectively is an integral part of doing science.

As technology advances and the Internet becomes a more pervasive aspect of the scientific world, the way science is done and presented will change. It is likely that most journals will either go fully electronic, or they will be forced to have an electronic version in addition to the printed journal. Hence, it is essential for all science students, irrespective of their field of research, to keep abreast of the advances in computing technology and of the way it affects their field.

### 3.7 Epilogue

Though good presentation is not a substitute for good science, good science must be presented well in order to have an impact. Fuzzy writing reflects fuzzy thinking [9], so improving the quality of presentation (writing) will improve the quality of thought and of the scientific argument. We have,

in this brief article, tried to present some basic principles that help present science better.

None of these principles, however, should be considered rules. Slavish adherence to these principles will succeed no better than slavish adherence to the principles of grammar. As noted by *Gopen and Swan* [1], there can be no fixed algorithm for good writing because too many reader expectations usually function simultaneously for any single structural decision to hold at all times, and because reader expectations can be violated to good effect. The best authors violate rules skilfully, but for this to work, they too must fulfil reader expectations most of the time to make the violations noteworthy.

Indian science students should also note that they must read good papers written in English. Correct positioning of words in a sentence and correct use of punctuation (in particular of commas and semicolons) is critical in English because English words, unlike words in many Indian languages or in European languages like Latin, are not inflected for cases. The position of a word often determines the meaning of a sentence, as in the following example [10].

*Only* I hit him in the eye yesterday.  
I *only* hit him in the eye yesterday.  
I hit *only* him in the eye yesterday.  
I hit him *only* in the eye yesterday.  
I hit him in *only* the eye yesterday.  
I hit him in the *only* eye yesterday.  
I hit him in the eye *only* yesterday.  
I hit him in the eye yesterday *only*.

Therefore, translating literally from an Indian language to English fraught with danger. If attempting to transfer a thought process in an Indian language to a manuscript written in English, be aware of the differences in grammar. Many books on English grammar are available, and a researcher would do well to have one of them by his side for consultation. We find the two small books by *Strunk and White* [2] and *Day* [10] particularly useful.

In conclusion, we note that merely reading an article on writing better will not enable one to write better, no more than reading a book on swimming will enable one to swim better. Improvement in writing will come by practice, and by making a conscious attempt to improve the clarity of thought and presentation. It will take effort to cross the 'dreary desert sands of dead habit'. A good way to begin writing better would be to take a manuscript you have written and attempt to improve it by applying the principles discussed in this article. Conscious application of the principles of good writing each time you write will gradually lead to their becoming part of your subconscious: clarity of thought and clarity of presentation will then become a matter of habit.

Treat your readers (including the reviewers and the editor) with the respect they deserve by striving to write well: you need them more than they need you to complete the process that is your research paper. Treat them with respect, and they will, in turn, treat your research paper with the respect you think it deserves.

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(Note: The printed version of the article was an earlier version and contained an error and did not include sub-section 3.3.6 on choosing an appropriate title. With permission from Prof. S.K. Tandon, convenor of the editorial committee of UGC, this corrected version is being made available.)