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Editorial

Writing a scientific paper: IV. Results and discussion

I have waited several months before writing this episode of my "Writing a Scientific Paper" series of Editorials. The reason is simple: each paper requires a different approach and each paper can have its own problems. Rather than write extensively about the subject (one could write a book) I have decided to illustrate this article using some examples, some of which are personal.

The Results and Discussion section of a scientific paper is the most important. Research is about results, and it is these that the reader has come to the paper to discover. It is on these results that opinions are formed and future research planned. I have previously indicated that the Introduction should be short, and much of the Experimental Details section relegated to "Supplementary Material" but the results, and the deductions the authors make from them, are paramount.

The first thing one must decide is whether results and discussion should be separate or combined. There can be no fixed rule, however, my experience is that it is better to separate them if it is possible to do so. In some cases it is necessary to discuss one set of results in order to logically proceed to one's next experiment or investigation, and in such a case the two are intertwined and separation is difficult. Here are some suggestions on how to write this part of your paper.

Present data clearly. The first thing one must do is to give a clear presentation of the results. If there are numerical data they should be presented in a sensible manner, either in table or graph form. There should be no need to do both, and one must always remember that it is now possible to present a graph, which is more immediately appreciated, in the paper and include the numerical data in a table in the Supplementary Material section. The writer should always bear in mind that while numerical data should be absolute, the discussion may be subjective. Another reader may have a different interpretation of the results.

Ensure results are sensible. One statement that I have had to make on several occasions is that if scientific data are acquired correctly the results should be sensible.

I recently received a paper claiming an improved product yield of 7474.3% more than previously reported results. My initial (cynical) reaction was that surely the calculator did not stop at five significant figures – most go to nine or more! I questioned the figure, and the author returned the paper, correcting it to 7474%. A little thought would have told the author that his claim was for a 75× increase. If his yield were the maximum 100%, it would mean that the best result earlier researchers had obtained was less than 1.4%. Surely something was wrong! Dependence on a calculator without thinking about the sense of the result was something I encountered often during my university career, and I am surprised to see how often it still occurs.

Distinguish the absolute from the subjective. While numerical results should be absolute, there are other results that are subjective. This is particularly true of e.g. microscopic observations. Many will know that I spent years examining neutron radiation damage in single crystal graphite using a transmission electron microscope (TEM). Several times colleagues told me "microscopists can prove anything". The reporting of such results relies on the integrity of the author. When I retired from active research I abandoned scores of unusual micrographs of things that had been observed only once, and for which there was no obvious explanation. They might have made interesting posters for an office wall but had no place in a scientific paper. I was once taken to task by a reviewer who wanted me to "prove" my observations and conclusions. My answer was that he had to trust me. I had more than a hundred supporting photographs, but could only include one or two in the paper.

Another criticism I faced was the question of whether the material had been altered by the preparation processes. In order to examine any material by TEM it is necessary to have a thin sample and there is always the possibility that the act of preparing the sample can somehow change what it contains. Is the TEM sample representative of the bulk? In graphite it is possible to prepare such a sample by simple cleavage (recently re-discovered by the graphene community!), but does the cleavage change, in my case, the distribution of the radiation damage observed? There is some evidence to suggest that this may happen.

Never extrapolate too far. My first research project involved looking at samples that had been irradiated in a high fluence test reactor. The act of irradiation was difficult. Samples could be inserted and removed from the reactor only when it was "shut down" and this was outside our control. The main purpose of our research program was to investigate physical property and dimensional changes in bulk synthetic reactor graphites and continuous monitoring was impossible. On one occasion we had samples that showed shrinkage when the first measurement was taken and growth on the next measurement. We had two data points in addition to the original. Did the material contract and then expand, or was the dimension oscillating, or doing something else? You can draw many different curves through three points!

Later techniques allowed measurements to be made at shorter discrete fluence intervals. The data points were now so close together that there was really no need to draw a line. It is now well known that the neutron irradiation of polycrystalline graphite can produce an initial shrinkage that eventually turns round to become a growth, which is a very important phenomenon for designers of graphite-moderated nuclear reactors to consider.

Today there is major interest in carbon nanotubes (CNTs) but precisely controlling their structural parameters is currently impossible. Many different parameters may be used to characterise them: diameter, length, number of walls, chirality, etc. I have seen several papers that contain results from only two different nanotubes with the authors jumping to unjustified conclusions. Let us say the authors examine CNTs with two different aspect ratios and find that those with the higher aspect ratio produce higher strength CNT/polymer composites. To now generalise, and say that the higher the CNT aspect ratio the higher the composite strength *may* be correct, but many more data points are necessary to validate the statement.

I used the following analogy to make this point to one author. I have two cars, both from the same manufacturer and both powered by gasoline (petrol). Any difference in performance is therefore not due to either of these two variables. Car A is faster than car B. What are some of the obvious differences between the two? Car A has a four-cylinder engine, two seats and metallic paint. Car B has a six-cylinder engine, five seats and non-metallic paint. Nobody would suggest that the fewer the number of cylinders in the engine, the faster the car! Similarly with the other parameters I have mentioned, but this is the “logic” that is behind some of the submissions received by CARBON.

Make discussion systematic. A big problem with many manuscripts is the way the discussion is allowed to ramble so that readers are never aware of where they are being led. Sometimes the conclusion comes as something of a shock! In today’s world of electronic gadgetry it is perhaps helpful to think of the “Discussion” of a scientific paper as having a similar purpose to a satellite navigation unit (SatNav). You use the SatNav to guide you from the origin of your journey to the place you wish to go, sometimes via selected landmarks. You expect the instructions to be clear and logical. You do not want the unit to take you round the world. While it might be able to suggest alternative routes and diversions, you usually use it to give you a route from A to B. In the same way the main body of a paper should lead the reader on a logical path from the results to the conclusions. The inclusion of too many diversions and alternative routes on a SatNav is confusing and annoying, and the same is true of a scientific paper. When you write your paper, “map out” a logical path and stick to it.

Learn from others. One thing that never ceases to amaze me is the fact that many submissions are prepared as if the writer had never read a good scientific paper, even though 50 may be cited! One sometimes wonders whether the author has ever read any of them carefully. As with many things in life, we can learn most from the experience of others and/or trying to do it ourselves, rather than from textbooks. You learn to write papers by reading other peoples’ papers, and by writing them yourself. I hope that Editorials such as this may help, but learning by doing is what is really important.

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