Structure of Reports

I. GOOD WRITING DOES MATTER

It is almost impossible to overestimate the importance of good scientific writing. The best experimenting in the world can be of little or no value if it is not communicated to other people and communicated well by clear and attractive writing. Our obligation to become as literate as we can is therefore not trivial, and it should be regarded as an essential and integral part of our experimenting activities. Our writing must be sufficiently good to attract and retain the interest and attention of our reader.

Although there is no list of explicit instructions for good writing, there is one principle that will make the production of good, readable prose more likely. There is one person whose interests must claim the writer's first attention, the person who will actually read the report. We probably have only one chance to influence him/her as he/she reads our report and the report must do it alone. We cannot stand beside our reader, adding explanation and clarification if he/she encounters difficulty in understanding what we have written.

We now consider the various sections of the report in turn, all as seen through the eyes of the reader.

II. TITLE

The *Title* is the first part of the report to draw the attention of the reader. It should not be too long, yet it should specify quite explicitly the topic of the work. For example, if the purpose of the experiment is to measure the specific heat of a fluid by using continuous-flow calorimetry, we can use this fact directly as a title: "Measurement of the Specific Heat of Water by Using Continuous-Flow Calorimetry." Notice that three questions are answered in this title:

1. Is the work experimental or theoretical? That is, are we reporting a measurement or a calculation?
2. What is the topic of the work?
3. What general method did we use?

Attention to these three items will almost invariably result in a good choice of title.

III. FORMAT

The sections of a report that are essential are the following:

Introduction
Methods/Procedures
Results
Discussion

These divisions can be used as a basic starting point. Headings should be concise. Subsections within each of these main sections should be used only when the length or complexity of the report makes them indispensable for clarity. Other main sections may be introduced in accordance with the requirements of particular experiments. Suggested possibilities are the following:

Theory
Sample Preparation
Uncertainty Calculations

The report should contain a clear, logical thread of argument, and we should not allow anything to disrupt that development of thought. If we feel that we must include some particular piece of description that is so lengthy and detailed that it would interrupt the smooth development of the main argument, we should consider making it an appendix to the report. In that way all the detail is available to any reader who wants it, but the main continuity of thought is not broken.

In the actual writing of the paper, sometimes the thought process flows more naturally if you write the sections in the following order: *Methods/Procedures*, *Results*, *Discussion*, and finally *Introduction*.

In all sections of the report it is important to properly reference previous experimental and theoretical work. It is often not possible to list all possible references; try to cite the earliest work on a given topic. It should be clearly stated which results are new and which confirm the results of previous (referenced) studies. Many arguments and bad feelings within the scientific community can be avoided if care is taken to do proper referencing.

Let us turn now to the details of each section of the report.

IV. INTRODUCTION

The various components that make up an informative introduction are, in order of presentation, as follows.

Topic Statement
Review of Existing Information
Application of Information to Specific Experiment
Summary of Experimental Intention

Topic Statement

With a good *title*, we can assume that we now have our reader's attention and that they have picked up the report. However, they are almost certainly starting from zero, or close to it, as far as our particular experiment is concerned. As they start to read, our first task is to orient their thinking toward the particular area of study. We are not going to succeed in this by diving immediately into unorganized detail about the experiment. Think instead of the most general statement that can be made about the experiment and state it directly. For example: "It is possible to measure gravitational acceleration by using the oscillation of a simple pendulum." In this way the reader is taken from his/her initial state of ignorance to direct awareness of the specific topic of the work.

Review of Existing Information

At this point the reader needs some reminder of the basic information relating to this particular area. We can meet this need by giving them a brief summary of the existing state of knowledge relevant to the experiment. The *Summary* may include, as necessary, some aspects of the history of the subject, a summary of earlier experimental work, or both. Two items are not discretionary and must be included in every report on an experiment. One is a clear statement of the system and the experimental circumstances with which the report deals; and the second is a description of the model or models used.

It is generally best to give this summary of existing information quite briefly for fear of obscuring the main line of argument, but it should be sufficiently detailed so that the reader can understand the rest of the report. In the interests of brevity and clarity, the derivation of standard theoretical results associated with the model should not be included. The behavior of the model, as represented by important equations, should be quoted, and *it is important at this stage to mention any assumptions contained in the model that may limit the validity of the equations*. To compensate for the omission of standard derivations it may be desirable to include in the references a source in which the complete derivation can be found.

Application of Information to Specific Experiment

The reader is now equipped to understand all that follows in the report, and his/her natural reaction at this point will be to wonder: "How does all this refer to this particular experiment?" We therefore supply a paragraph or two to show how the basic information, such as an equation representing the behavior of the model, can be converted to provide a foundation for our particular experiment.

Commonly, this involves some procedure such as putting the basic equation into straight-line form (or some suitable equivalent) and identifying the ways in which the model can be tested against the system. We can also point out at this stage the information that will become available from the parameters of the graph (such as slope and intercept in the case of straight-line plotting). The reader thereby becomes fully aware of how our final answer will be obtained.

Summary of Experimental Intention

It is helpful to the reader to conclude the *Introduction* with a summary of our specific intention in the experiment. Such a statement is satisfying to the reader because, particularly in a long and complicated experiment report with a lengthy introduction, it offers him/her a review in summary form of the whole course of the experiment, and it enables them to make sense of the subsequent description of the actual conduct of the experiment.

Statement of Experimental Purpose

No mention has yet been made of the traditional statement of purpose for the experiment. It has been omitted so far because, although it should appear somewhere in the *Introduction*, there is no universally suitable location. If the topic of the experiment is familiar, the statement of purpose can form an acceptable topic statement right at the beginning of the *Introduction*. On the other hand, the basic purpose of an experiment might involve matters so complicated and unfamiliar that a statement of it would be completely incomprehensible unless it followed a substantial amount of preparatory material. It does not matter a great deal where the statement of purpose comes, so long as it is included and comes at a point in the *Introduction* where it fits well and makes good sense to the reader.

The *Introduction* has performed a number of services for our reader. Right at the beginning the topic statement has directed their attention to our particular area of work. They have then been reminded of the existing state of knowledge in that area. Next they have been shown how that applies to our particular experiment. Finally, they have been given a concluding summary of our specific experimental intention. They are now ready to hear how we actually did the experiment.

V. METHODS/PROCEDURES

The report's introductory section takes the form of a descriptive sequence that proceeds from general to specific. We start with a topic statement that is the most general remark about the experiment we can make, and we end with a completely specific statement of intention. Such a sequence is designed to suit the reader's requirements in the introductory section, and a similar sequence is equally suitable for the *Methods/Procedure* section.

Outline of Procedure

To set the scene for the subsequent description of the details of procedure and measurement, we first offer the reader a review of the whole course of the experiment.

For example, if the experiment really consisted of the measurement of the variation of electrical resistance of a copper wire with temperature over the range 20°C to 100°C, we say just that to provide the reader with a framework into which he/she can fit all subsequent description of detail.

Specific Measurement Details

Now that the reader knows the general course of the experiment, he/she is ready to be told the specific methods by which we measured each of the required quantities, carried out sample preparation, and performed other steps. This can be done quite simply by stating each in turn until we have completed the list. We must make sure that no significant method of measurement is omitted. If a quantity in the experiment could be measured by using some standard and familiar technique, it may be sufficient to mention it by name. If we feel it is unusually significant, we can discuss at this stage the accuracy of any particular measuring process, while remembering that the overall precision of the experiment is a different topic that will appear in a subsequent section of the report

Precautions

After the reader has learned the methods by which we made each measurement, he/she may recall the difficulties or possibilities for error that are inherent in particular procedures. He/she therefore needs reassurance that we, too, had thought of these possibilities and had been sufficiently careful to take the necessary precautions. As we offer that reassurance, however, we need not go to extremes. Care should obviously be taken with all measurements; there is no point in making superfluous claims to virtue in describing routine and obvious precautions. There are times, however, when special care to avoid some particular source of error is a genuinely important part of the experiment, and it is reasonable to draw attention to this before we close the procedure section.

Apparatus Diagrams

Good diagrams of experimental apparatus are an essential part of any good report. Neatness and clarity are important and good, legible labeling assists enormously in understanding the experiment. Good diagrams can also help experimenters to write reports. Reference to a good, clear, well-labeled diagram can save paragraphs of written description and provide detail that would be intolerably tedious to read if it were included in the text.

Reference to diagrams can be inserted at any appropriate point in the text, but reference to a general diagram of the apparatus as a whole can make a convenient beginning for a procedure section.

VI. RESULTS

Measured Values

At this point in the report, the reader has all the information he/she needs for understanding the experiment, and he/she is ready to receive the results directly. Because any good experiment almost inevitably involves the variation of some quantity with another, the results are usually best presented in a table. The headings should be explicit and should include, if possible, the name of the variable, its symbol and the units of measurement. Attached to each numerical entry should be its uncertainty, unless some separate discussion of uncertainties makes the precision of the measurements absolutely clear. Tables should be clearly identified with a table number and a title.

Description of Measurement Uncertainties

The report should state explicitly the kind of uncertainties we are quoting. These are likely to be either estimated outer limits or statistical quantities such as a standard deviation or a standard deviation of the mean. In the case of statistical quantities, we must not omit mention of the number of readings in the sample from which the results were derived. If any quantities in our list of measured values were obtained by computation from some basic measurement or measurements, we must state clearly the type of calculation used to obtain the final uncertainty in the computed quantity.

Computation of Final Answer

If the experiment has been well designed, we will probably obtain our final answer by some graphical procedure. It is now time to tell the reader exactly what that procedure is. In simple cases we may obtain the answer from the basic graph of one measured variable against the other, but even then we must be explicit about what we have done. The readers will wonder what kind of calculation we performed to obtain the uncertainty in the final answer. We simply say what we have done. We can add, if necessary, that the basic uncertainty was combined with other uncertainties, and state explicitly the method of calculation. If we obtained the result by a least-squares calculation and incorporated any other standard deviations to obtain a final value for the uncertainty of the answer we again state simply what we have done. Throughout the *Results* section of the report, we do not trouble our busy readers with unnecessarily detailed calculations. The reader trusts us to do simple arithmetic, but he/she want to know what kind of calculation we did. If we feel compelled, for some particular reason, to offer an unusual amount of detail regarding such calculations, we can always put it in an appendix where it will be available if wanted but where it will not obscure the clarity of the main report.

VII. GRAPHS

Graphs in the report differ from the graphs used in doing the experiment. Those graphs were working documents designed as computational aids. For a precise experiment, the graphs are possibly quite large and finely drawn to permit precise extraction of information. On the other hand the graphs in the report serve mostly as illustrations. They allow the reader to see the behavior of the system so that he/she can judge for himself/herself the validity of our assertions about the results.

The graphs in the report must be clear, neat, and uncluttered so that reader does not have to work too hard to get the message. The points on the graphs should have their uncertainties clearly marked on them (by a box or a cross), and the axes should be clearly labeled. Both the type of uncertainty and any symbols used in labeling the axes should be explicitly identified in some obvious way in or beside the graph. Do not however, fill up empty spaces on the graph with arithmetic calculations of slopes, and the like. Each graph should obviously have a clear title or, as is common in printed publications, a more extended caption.

VIII. DISCUSSION

Comparison Between Model and System

The *Discussion* is an integral part of the report and not an afterthought. Here we compare the relationship between the system and the model. The outcome of that comparison is vital for the experiment. Remember that, in evaluating our results, we have to disengage ourselves from our hopes and aspirations for the experiment and accept objectively the actual outcome, so now, at the reporting stage, we must make a candid and unbiased statement of that outcome. We should make it a plain, a simple statement of the actual situation. Because such a comparison was the fundamental objective of the experiment, it is necessary for its outcome to be clearly, factually, and prominently stated. In the report we shall be proceeding quite soon to matters of interpretation and opinion, and it is important that we start the *Discussion* section with a plain statement of the actual, indisputable outcome of the experiment. That statement will raise some questions in the mind of the reader, and we must turn our attention to them now.

Consequences of Discrepancies Between Model and System

One of these questions concerns the possibility of error in the final answer that could be caused by failure of correspondence between the system and the model. The reader needs reassurance that we have protected the final answer from that kind of error. We should point out, for example, that an unexpected intercept will not contribute to error in a quantity that has been obtained from the slope alone, or that a systematic departure from linearity over part of a graph did not invalidate an answer that was obtained from the linear segment only.

Speculation Concerning Discrepancies Between System and Model

In describing the report's earlier sections, we have stressed objective and factual reporting of the actual situation. Matters of opinion or conjecture should not have played a significant role in those parts of the report, and we have probably limited ourselves to such statements as would have been made by most impartial observers. Now, however, comes a stage at which we not only can but should introduce our own ideas. Our reader has in turn been informed about the actual degree of correspondence between the system and the model, and he/she has been reassured that the final answer has not been contaminated (as far as we were able to tell) by any failure of correspondence between the system and the model. Because we have met our basic obligations as experimenters, we could quite justifiably leave the report there. However, the interest of the reader will doubtless have been aroused by the description of any discrepancies between the model and the system. We presumably started with a model that was chosen to suit the system as closely as possible. If any failure of correspondence between the system and the model had been anticipated, such breakdown would have been incorporated into the experiment design. Any observed failure of correspondence, therefore, is bound to attract attention, and the reader will want to know what we think about it. We are more familiar with the experiment than anyone else and are in a better position than others to guess at the origin of discrepancies.

Sometimes a discrepancy has (at least superficially) an origin that is easy to identify. At other times, however, more comment is needed. If the situation is genuinely puzzling, we may not be able to offer much in the way of speculation, but it is always worth trying. As has been said, as the experimenters, we have better chance of speculating fruitfully than most others, and our ideas are almost certainly to be of interest and possible value to other workers.

Sometimes, however, despite our best efforts we fail and are unable to offer any constructive ideas. We must be completely honest. If we are are dealing with a well-tested, reliable model and if we have tried and failed to resolve a failure of correspondence between them, our situation cannot but be of interest to other workers. We should tell them about it, and perhaps we shall all learn something from the resulting discussion.

Generic Writing Scientific Paper outline

I Introduction

Objective, theory/background

Topic Statement

Review of Existing Information

Application of Information to Specific Experiment

Summary of Experimental Intention

Statement of Experimental Purpose

II Methods/Procedures

Apparatus figures and diagrams

Outline of Procedure

Specific Measurement Details

Precautions

Apparatus Diagrams

III Results

Key tables and graphs

Measured Values

Description of Measurement Uncertainties

Computation of Final Answer

Graphs

IV Discussion

Comparison of experimental results and prediction, what went wrong, and how to improve

Comparison Between Model and System

Consequences of Discrepancies Between Model and System

Speculation Concerning Discrepancies Between System and Model