What a lab report should contain

Last updated by Dr Andrew French. 4th February 2015

The purpose of a lab report

1. To record a piece of experimental work sufficiently clearly that *someone else* could *repeat* the experiment *without your help*. If you achieve this, chances are you will be able to re-read your report at some point in the future and be able to follow what you did.
2. To capture observations of phenomena, ideas, design improvements etc in the context of a structured experimental methodology. This is what makes a lab report real science and different from reading a textbook and solving a pure mathematics problem.
3. To add to the body of scientific knowledge. An experiment which achieves its aims elegantly is fundamental component of what we call Science. It may have many educational and technological applications, some of which may not have yet been exploited. A really good lab report contains the design for an experiment which allows one to explore curiosity driven questions like: “Why is the sky blue?” “What is a rainbow?” “What is the motion of a football?” It also can serve as the blueprint for new technologies which arise out of observed physical phenomena and or novel practical techniques for reducing errors and making small effects measurable. The entire modern wireless communications industry can be traced back to the pioneering experiments of Hertz, Marconi, Tesla etc, which probably occurred in a fairly modest laboratory and were written up in a tatty and ink stained lab-book just like yours.

The structure of a lab report

Essentially, a lab report provides description of experimental work conducted under headings of *What, Why, How/Where/When/Who, What next.* In other words, *what* have we measured? *Why* did we endeavour to measure this effect? Was it to repeat another observation, or to test the predictive power of a theoretical model? If it was a model, what effects were ignored? What is assumed to be true? How did we go about the experiment? Who conducted it and in which laboratory and when? What were the specific practical details of the equipment used? What were the sources of error in measurement? Were there systematic errors which affect *accuracy* (e.g. did we start the clock when we meant to or was there an offset?) Were there random errors which effect *precision*? Could we quantify these errors via some form of statistical analysis? Finally, from what we have learnt, what would be the next investigative step to augment our understanding?

To make sure we cover all these aspects, a structure is recommended. This also helps the reader of the report (which is good practice to assume is *not* the author). A report is essentially a piece of *communication* as well as historical evidence. We should aspire for **maximum clarity and ease of information extraction.** This means creating a multi-level report where the key points can be readily drawn out, e.g. when glancing at graphs and the conclusions. Assume a really busy and easily bored person that has a strong impact upon your financial future has to read your report, and has a very short amount of time to make a potentially life changing decision about how competent you are....

Suggested structure:

0. Abstract

For big reports, conference proceedings, theses etc you might want to provide a short 100-500 word summary of the entire scientific work undertaken. This includes the aim, a summary of what was done experimentally and then the conclusions drawn. Assume most people will only skim read this, and possibly your conclusions. They won't read the rest of the report unless the Abstract convinces them that the extra effort is worthwhile.

1. Aim

State very clearly what the experiment is trying to achieve, and why. Ideally write in the future tense, as your aim should ideally pre-date your experiment!

For example: *"This report describes an experiment to record the dynamics of a compound pendulum which forms the basis of an ancient Grandfather Clock owned by the Physics department of Winchester College. The frequency and amplitude of oscillations of the pendulum are to be measured using a data logging device and compared to theoretical predictions based upon calculations of the moment of inertia of the pendulum. The experiment will hopefully allow us to explore the practical validity of the Simple Harmonic Motion Mathematical model of small oscillations, and therefore enable us to better understand the variety of physical scenarios where this model might be applicable."*

2. Experimental method

What are you trying to measure? (e.g. the displacement vs time trace of the end of an oscillating pendulum).

How are you going to measure it? (e.g. via a data logging device driven by an automatic video camera based tracking system targeting a red spot painted on the pendulum bob .... Or perhaps by writing down the time of every ten oscillations in a lab book).

What specific practical details are germane to the experiment? (e.g. the geometry and masses involved with the pendulum. The nature of the pivot point and its frictional characteristics. Do you use a lubricated precision engineered clock mechanism, or are you hanging the pendulum from the rough end of a retort stand?) What are the sources of experimental error? Have you done anything in the design to minimize these? Are there any unwanted effects? (e.g. precession of the pendulum, the pendulum hits the retort stand for large oscillations etc).

3. Theoretical model

What do we expect will happen, based upon the Physics we know? Can we construct an idealized mathematical model involving parameters associated with the experiment? (Masses, times, lengths, velocities etc). We should define this 'Universe of parameters' in a **diagram** and then use Laws of Physics (e.g. conservation of energy, mass, momentum, Newton II etc) to generate mathematical relationships between them. (e.g. "The period of the pendulum varies as the square root of the length"). State any *assumptions* inherent in the model, and try and justify why certain real physical effects (such as air resistance, internal motion etc) that your *model doesn't include* are 'second order effects' and can be *safely considered irrelevant.* Remember, most real-world physical effects have non-linear terms and *cannot* be solved analytically (without some form of approximation) by the mathematical tools you will learn at School and University. We therefore tend to select systems to investigate which mostly behave in the ways that our mathematical analysis can explain and predict. *Always justify* why the 'potentially solvable model' is appropriate, rather than *assert* the validity of the solvable model just because you haven't the tools to deal with a more complex reality. Unless you think like Plato, the models of Physics are an idealized *approximation* of reality, not the other way round.

4. Analysis method

How are we going to turn our measurements into *information*? How are we going to quantify errors? What sort of statistics are we going to employ if we have the luxury of repeating the experiment? Are we going to plot a graph? If so, a Line of Best Fit (i.e. 'Linear Regression Analysis') is a useful aid to inferring relationships between parameters as we can always work out a 'degree of fit' via a *Product Moment Correlation Coefficient.* (This is what the R^2 value in Excel is all about. Look up the Mathematics if this is new to you). Therefore we need a model which predicts a *linear relationship* between certain *groups* of parameters. e.g. "The square of the period (T) of a pendulum is proportional to the length (l) of the pendulum string". So plot T^2 vs l on a graph, you might see a straight line relationship. If not, something possibly interesting, or professionally embarrassing, may have occurred.

Are we going to do calculations by hand, or do we need to design a spreadsheet or computer program to do many repeated calculations for us? This might be a minor issue for a double-hour Sixth Form Physics practical, but a major issue for a large scale experiment like the Large Hadron Collider which will generate more data than most normal computers can handle.

5. Experimental log & 'results'

This is probably the *most important* section. Here you describe the historical account of what you did and what observations you made. It is best done *in the moment*, so all details can be recorded. This is why most laboratories *insist* lab books are *kept in the lab*. Small details which seem irrelevant at the time may prove to be very interesting following later analysis! By all means write measurements in a table, but it is highly recommended that any graphs should be *plotted as you go along*. This means you can get an idea how your Aim is being met, whether what you see is as expected or not. Crucially, are you taking measurements over the correct range of variables? Are you recording voltage measurements in 1 μV increments between 0 and 0.01V when all the interesting effects occur between 6V and 10V? You can efficiently work out an *appropriate scale for your graph* and an *appropriate range of measurements* to take following a *quick sweep of behaviour over the full range* of your experimental kit.

Did you make any experimental changes as you went along? **Record these!** e.g *"I observed that the angle of my slope was too steep and my rolling cylinder was prone to slippage. Since my model assumes no slippage, I therefore conducted all my subsequent experiments at a* 10^o *angle, and at no point observed any further slippage."*

Even if all manner of things go wrong in your experiment, record what you did. You (or the next person who conducts the experiment) will not make similar mistakes next time, unless for harshly educational or comedic purposes. (Your microphone hits limit due to excessive volume, a physical phenomena your model ignores turns out to be really significant, your rocket escapes your test rig, and the Physics department, due to lateral movement and you hadn't thought about using some guide rails to confine it...)

6. Analysis and presentation of data

Unless the lab report is deliberately qualitative, for example an 'eyewitness' description of an erupting volcano (!) the analysis section will typically describe the degree of correlation between a *measured* numerical relationship between physical parameters and a predicted theoretical equivalent. As discussed above, this is often achieved by plotting a Line of Best Fit and then working out a Product Moment Correlation Coefficient.

If the correlation is suitably 'good' (i.e. the magnitude of the Product Moment Correlation Coefficient is close to unity) then one can make modest claims about the validity of the model. Try not to overstate - be *sceptical* and *rigorous* and *always back up claims with numbers.*

It is always good practice to try and *quantify any errors* that you encounter in measurements made. Note a combined quantity such as $\frac{v^2}{r}$ will have a more complex dependence upon the errors of its component parts (v and r) than simply the sum of these. Error analysis can be approached mathematically by considering the *upper and lower bounds* of a measured quantity.

e.g.

$$\begin{aligned}&2.5\text{ms}^{-1} \le v < 3.5\text{ms}^{-1}\\&10\text{m} \le r < 11\text{m}\\&\therefore \frac{2.5^2}{11}\text{ms}^{-2} < \frac{v^2}{r} < \frac{3.5^2}{10}\text{ms}^{-2}\\&\therefore 0.57\text{ms}^{-2} < \frac{v^2}{r} < 1.23\text{ms}^{-2}\end{aligned}$$

Note if you are Mathematically inclined, you might want to consider *The Laws of Error Propagation*, which assume *Gaussian* errors. This will typically give you a narrower error range as the tails of the distributions of each variable are ignored, and assumed to be symmetrically distributed about the mean average of the measurement.

If your errors are significant, plot them on your graph using *error bars*. A strong correlation is only believable if your error bars are *not significant* on the scale of your graph.

Graphs and figures should *always be 'self contained.'* This means they should contain sufficient information *for the graph to be understood without reference to anywhere else in the report*. Label axes, give the graph a title, explain lines and points using a colour coded *legend* etc. Give the graph a caption with some words of *explanation*. Personally, I suggest you employ this 'self contained' technique more widely in your report. Assume most people will skim read your work and will want to get at a very specific piece of information and don't have time to read your entire missive. *Only* refer to equations that you can actually see on the same page!

Although the Line of Best Fit is often the sensible way forward for quantitative comparison of theory and experiment, it is also often useful to *plot the actual measurements* e.g. voltage vs current, velocity vs time etc. If your theory predicts a straight line relationship of quite complicated functions of variables, it is important that you get a feel for the *actual relationship that you are investigating* and the general trend of the curves that describe it.

Use *percentage difference* to compare differences between theory and predicted values. e.g. your experiment is designed to give you a single number like the gravitational force constant *G*. If you make repeated measurements, you can compare the difference to the expected error range. If your theory vs measured differences are within this range, you have a positive argument for the validity of your model.

7. Conclusion (Summary, Critical review, Suggested next steps)

This should be a summary of what you have done and the results of the analysis.

- I would always use bullet points.

Always use numbers to justify conclusions if you can and avoid fluffy and ambiguous statements such like "agreement was good" (unless you define precisely and quantitatively what 'good' is!) e.g. "*We found the textbook value (9.81 ms^{-2}) of gravitational acceleration was within our measurement range of 9.75ms^{-2} $< g <$ 9.85 ms^{-2}* " is much more informative than *"Our measured value of g seemed to agree with the textbook values."*

Finally, you should *review your experiment critically* and suggest *possible improvements* that the next person who conducts similar work should consider.

Science is always a work in progress and your experimental report will form part of a continuous narrative that extends through the ages. If scientific work is properly documented, then one can hope that future generations will have a more refined understanding of the Universe than ours, as they will be able to build upon and extend the knowledge that has been acquired in the past.

AF. 5th February 2015.