Chapter 2 The Process of Writing a Laboratory Report

Sometimes the most difficult step in doing something is getting started. That can certainly apply to Laboratory reports. This chapter attempts to help the student by suggesting a step-by-step process for developing the laboratory report. This allows focus on each particular step, rather than feeling faced by the immensity of the overall task all at once, a real Impediment to getting started.

The material in this chapter is presented two different ways. First, a flowchart is shown, as Figure 1, which shows the overall process. In the rest of this chapter, the same material will be presented in a more detailed text form. Reference will be made to other parts of this Manual which for particulars relevant to that stage of the process. Because of this step – by step description, sections of this chapter will be numbered for reference, since frequently it will be necessary to say, “Go to section x” rather than following with the next block of text in linear fashion, as with a normal text document.

It is assumed that, as you read this, the laboratory itself is completed, the data is in hand, and you have done the calculations with the data that show what the laboratory exercise is intended to show. You know whether things turned out as expected, and if not, you have done some debugging and investigating, perhaps even some extra simulation, to explain things. All this ought to be completed either before you start to write. However, very likely, as you write, new ideas may occur to you that will find their way into your report. That is part of the value of the writing process. The act of writing helps one think about what has happened and how to understand it.

The approach taken here is basic. You may have a laboratory exercise that will require variations and elaborations on what is described here. Other chapters, Chapter 2 on organization and Chapter 5 on what to do if things don’t work, address such issues.

1. Basic Outline

Construct a basic outline for the laboratory report. This will depend on what kind of report you are writing. An “Experiment” tests a hypothesis to see if it is true. A “Characterization” seeks to measure and analyze some component or system. A “Design Exercise” develops and tests some system. Depending on which of these you are doing, a basic outline can be chosen from 1a, 1b, or 1c below in Table 2-1. Make sure your outline complies with any reporting instructions from your instructor.

Table 2-1 Basic Outlines

1a. Experiment	**1b. Characterization**	**1c. Design Exercise**
Abstract	Abstract	Abstract
Introduction/Hypothesis	Background	Background/Specifications
Procedure	Procedure	Design/Simulation
Results	Results	Procedure
Analysis	Conclusion	Results
Conclusion		Conclusion

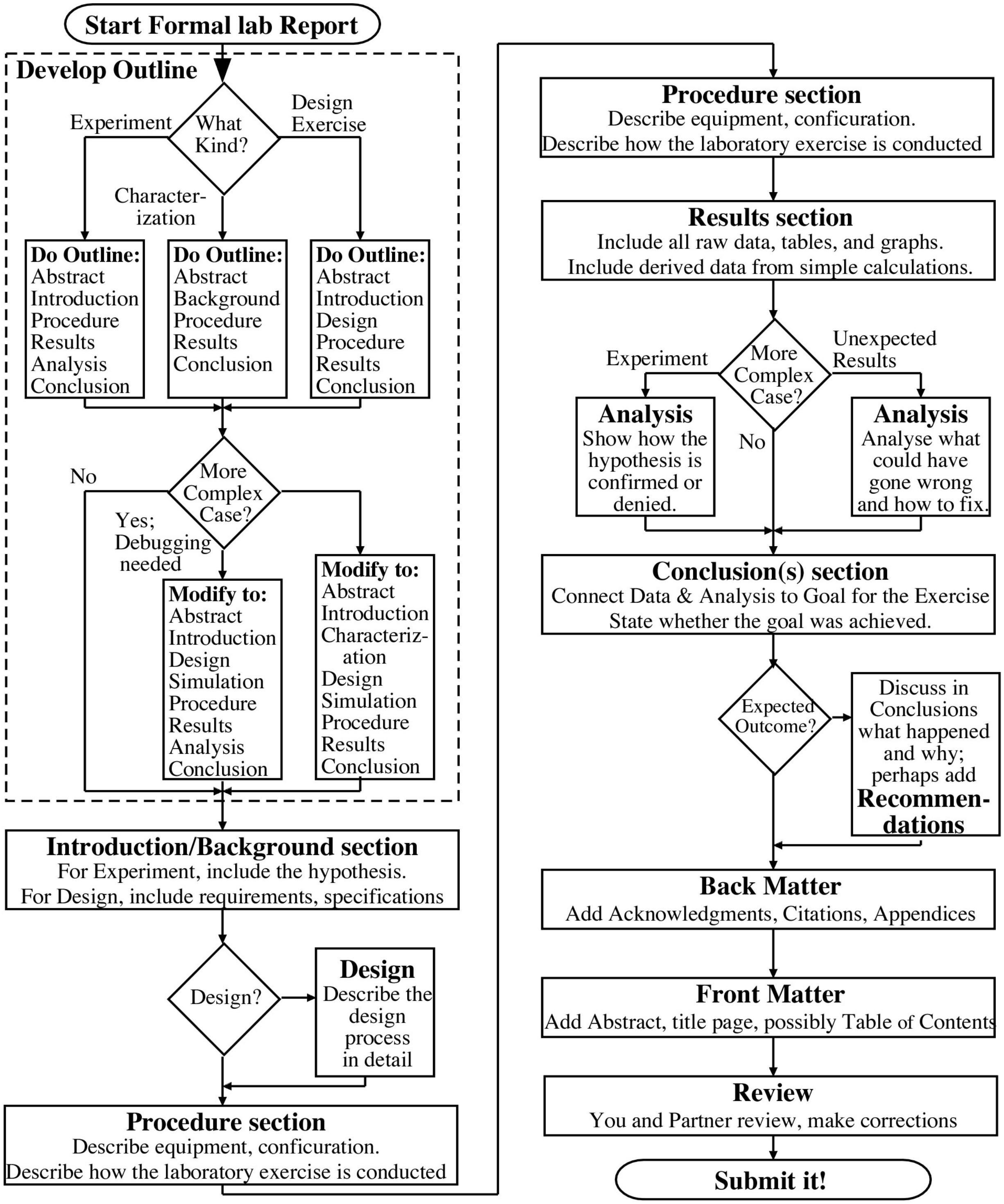

Figure 2-1 Laboratory Report Writing Process

Chapter 3 on Organization describes the general contents of each of these sections, and the differences between the different kinds of reports. Whether sections marked with a "/" should be one section or two will depend on the length and elaboration necessary. For example, in an experiment, if the hypothesis to be tested can be stated very simply, such as a simple formula predicted by theory, the hypothesis can be included in the Introduction (or Background). If it is more elaborate or nuanced, and needs discussion, the hypothesis may need to be put in its own separate section. As shown in 1a above, an Experiment is given a separate Analysis section because it is usually necessary to do some data manipulation to see if the hypothesis is true, such as graphing the data and finding the goodness of fit to a relationship predicted by the hypothesis. That may also be necessary for a Characterization and Design.

2. **Modified Outline (or skip ahead to 3.)**
   Are there circumstances or particular features of the laboratory exercise that require modification of the basic outline? For example, a two step design exercise, where a characterization must be done on a component before designing a system using it, would require a separate procedure and results for the characterization before the design, procedure, and results sections from outline 1c above. A design that doesn't work may require an analysis section after "Results" that determines what went wrong, and a "Recommendations" section after "Conclusions" that suggests what can be done to fix the design. These possibilities are given in Table 2-2 below. A Design Exercise is more likely to require such variations, but similar kinds of things can happen in an experiment or characterization too, though less often.

Table 2-2 Modified Outlines for Special Circumstances

2a Design with Characterization	**2b Design with Debugging**
Abstract	Abstract
Background/Specifications	Background/Specifications
Characterization of Component	Design
Results of Characterization	Simulation
Design	Procedure
Simulation	Results
Procedure	Analysis
Results	Conclusion
Conclusion	Recommendations

3. **Write the Background (or Introduction) section.**
   Notice that we do not start with the Abstract. The Abstract is the last part of the report to write. Whether you call the first section "Background" or "Introduction" may be prescribed by your instructor, or it may be a matter of choice. "Introduction" describes what the exercise is all about – why it is being done. "Background" furnishes information on the scientific or engineering issues or components, and may include introductory information. In a lengthy report it may be appropriate to include both. Either way, you need to start by explaining what the exercise is and what it is supposed to show. For an Experiment, you must state the hypothesis and describe how you will know whether or not it will be found to be true. In a characterization, you need to describe the parameters that you are trying to determine, and perhaps how they fit into the model of the device or component being characterized. For a design exercise, you need to state the specifications for

the system you are designing. What is it supposed to do, and what performance parameter values is it supposed to reach?

Write in third person, passive voice. Paragraphs should be relatively short and limited to one thought, usually defined in the first sentence. Keep sentences as short as you can. See Chapter 4, Style, for a further discussion of this. You may need to include some figures for illustrating the system or its components. Chapter 5 has some suggestions concerning figures. The sections on schematics and other figures may be helpful. Schematics, diagrams, and graphs are very helpful in conveying to the reader the nature of the system or device, and what it is expected to do. Often specifications are best understood in a diagrammatic form, such as the bandpass for an amplifier, or the poles in a stability diagram for a control system.

By the end of the Introduction/Background section, the reader should understand what the laboratory exercise is all about and what it is expected to show.

4. Design (If not a Design Exercise, skip ahead to 5.)

4.1 Design constraints

At this point the reader should know what you are designing and what performance parameters you are trying to meet. Specifications of design constraints, such as power supply Voltage, or limitations on components to be used, should be stated here if not given in Background. You may be constrained to use a particular spring, for example, so its characteristics need to be stated. Any further specifications and design constraints of this sort should be in a separate paragraph.

4.2 System notional schematic / configuration

Present a diagram of the system to be designed, showing its components and how they interact. (In a complicated design exercise, there may be alternatives to be presented and discussed; we'll assume a simpler case here.) Usually the system is presented first, here, with notional values for components that must be selected. For example, an amplifier may have resistors marked "R_B" or "R_C" but with no values attached. Determining those values is part of the design process.

4.3 System performance metrics and derivation

The calculation of expected system performance given notional component values needs to be presented. This can be done here or after choosing the component values. Doing this first is usually better since component values are chosen to optimize (or satisfy) these formulas. To use the amplifier example, a key performance parameter is Voltage gain, A_V. So, this is where you would show how that is calculated using a numbered equations:

$$A_V = g_m (R_C \,||\, R_L) \qquad (1)$$

In like manner you might give the formula for the damping factor in a control system or final velocity for a railgun design. The numbering is important, because after components are chosen, a calculation is made using this formula to give the performance predicted by theory. In a complex case, you may need several paragraphs.

4.4 Component Selection

This is a paragraph, or many paragraphs, where you step through the design process, describing how you chose the components for the design that you did. How did you choose the resistor R_C? Or the diameter and length of your Stirling engine cylinder? Or the mass of explosive to use for the gun? Usually these choices derive in some manner from a design specification, such as the desired gain of the amplifier, the power to be delivered, or the projectile velocity. For example, in the amplifier design problem:

$g_m = I_C/V_T$, where $V_T = .026V$, and $I_C = (V_{CC}-V_C)/R_C$, where perhaps V_{CC} was specified to be 12 Volts. Choosing V_C = 8 Volts, then calculation of values can be shown. If the target A_V is 50, and some suitable (and available) R_C = 1.0 KΩ is chosen, then the calculation is made to show that the design meets the desired A_V:

$$A_V = - g_m (R_C \,||\, R_L) = (4.0 \text{ mA} / .026 \text{ V}) (1.0 \text{ K}\Omega \,||\, 1.0 \text{ K}\Omega) = - 77$$

In some cases, component values will be derived directly from some circuit (or other system) parameters. Such as:

$$R_{B2} = (V_{CC}-V_B) / (I_B + I_{RB1}) = (V_{CC}-V_B) / (I_B + 10\, I_B)$$
$$= (12V-4.7V)/(.02mA+.2mA)$$
$$= 33.2 \text{ K}\Omega$$

(The nearest standard value, 33 KΩ, was chosen.)

Since your design work was done before the laboratory exercise, and you are writing about it after the exercise, all of the design calculations have already been done, it's just a matter of formally writing to describe what you did. In some formal laboratory reports, some of these detailed design calculations may be relegated to an appendix, with only the most important given in the body of the report, such as calculation of the achieved Voltage gain for the amplifier example. (The calculation of bias resistor values to achieve that collector current is secondary, and less important.)

4.5 Final design and performance

At the conclusion of this section, you should include a diagram or schematic of the system with all the component values filled in, that is, the completed design. You should also have shown that, by theory, the design should achieve the specified performance. Or, if it does not achieve the specified performance, you should explain why.

5. Procedure

This is the section in which you describe what was done in the laboratory. If some design of the system or the experiment was necessary but relatively brief, it can be included in this section. Otherwise, it belongs in an earlier design section.

5.1 Exercise equipment configuration

This is a paragraph describing how the laboratory equipment was used and configured for the exercise. Describe the laboratory equipment. Usually you must give the make and model number, and perhaps even the serial number, for each piece of equipment that you use. It may be necessary to also give specifications for the equipment, such as the accuracy or resolution of the instruments, the frequency limits of a meter, or the maximum Voltage that can be measured, if those are relevant. If it is not obvious, describe how the instruments are connected to the system being measured or characterized. Identify ground nodes, mechanical reference points, and other points of origin if they are not clear. It may be required that you specify the date and time of the exercise, and the room number or facility in which the exercise was conducted. Check your instructor's requirements for the laboratory reports. You should not normally have to give a step by step account of how the system under test was assembled. Such details are not important, and are implied by the system diagram or schematic.

5.2 Exercise Operation

Describe how the exercise was conducted. This includes instrument settings that vary, and measurements made. There may be a lengthy sequence of different operations. The extent of detail here will depend on circumstances. It is important to describe anything you do that is not obvious. Routine steps that result in what will later be a table of data do not need to be described in any detail. Generally, each step that you describe here will correspond to a value or a table of data in the results section.

6. Results

This is the section where you give the data collected during the laboratory exercise, usually in a tabular form. You must use text, describing what the data are (corresponding to the procedure steps) and calling out the tables for different data that are collected. It's important to use appropriate units and numbers of significant digits.

6.1 The raw data (and simple calculations)

The raw data as collected in the laboratory must be shown. If there are calculations based on that data, they can be shown as well in the same table. For example, if Voltage and Current are measured to find the Impedance, the table should show the calculated Impedance values as well. If the laboratory exercise had several different sequences of measurements, this section should be subdivided accordingly.

Often it is appropriate to present a graph of the data at this point in the results. Doing a good graph that communicates clearly is important. See Chapter 5 materials on graphs for further information.

If there were problems in collecting the data, or surprising conditions, or aberrant individual samples, it is appropriate to note that in the Results section, though perhaps with any involved discussion to come later.

6.2 Processed results (or Analysis section)

If some elaboration or computation with the data is needed before reaching conclusions, it is appropriate here. In some cases, particularly an experiment, it may be that this step should come in a separate Analysis section. For example, conversion of separate Voltage, Current, and Phase measurements into a complex impedance would be a processing step. Similarly, calculations for inferring pole and zero positions for an amplifier or control system would require computation or careful analysis of the observed data. The point of processing the data and doing computations is to bring information to bear on the purpose of the exercise. Is the hypothesis confirmed? What are the key characteristics of the system? Did the design meet its specified goals?

If there are specifications or simulation results to which the experimental results from the laboratory can be compared, this is where that comparison should be done. For an amplifier, what were the predicted, simulated, and actual Voltage gains? What were the predicted, simulated, and actual high frequency cutoffs (f_H) for the control system? Use graphs to illustrate these key findings. (If the frequency or some other parameter varies over multiple orders of magnitude, you should probably be using some form of logarithmic plot.)

7. Conclusions

In a best-case laboratory report, the Conclusions section is short and sweet. Citing the goal to be demonstrated, and citing Results, the Conclusions describes how the results show that the goal of the laboratory has been achieved. For an experiment, the hypothesis is demonstrated to be true (or false). A component or system has been characterized and the results meet expectations. A design has been implemented and assessed, and its performance both meets the specifications and is consistent with design (and simulation) expectations. If the instructor requires that the outcome of the laboratory be witnessed, a statement should state the date and the name of the witness, usually the instructor.

If the results are not consistent with the goals of the laboratory exercise, things are more complicated. Chapter 6 discusses this situation at greater length. Briefly, an explanation needs to be given. That may mean adding another section to Results (and to procedure) describing what you did to try and find out what happened – your investigation into the problem. If you only realized that you had a problem after the laboratory work was done, then you can't go back and add to procedure and raw lab results, but you can do analysis, perhaps even some simulation or analytic modeling, that will shed light on the issue. Your treatment could extend to posing several hypotheses about what went wrong and how you tested each, to arrive at either a conclusion or your best assessment of remaining possibilities. Such an investigation probably deserves to be a separate Analysis section. Ultimately your conclusion will be that the system did not produce the expected result, but you can give an explanation, or a number of possible explanations, with supporting analysis results. These can lead to adding a Recommendations section on how to correct the problem and perhaps how the problem might be avoided in the future.

8. Back matter:

Compile your acknowledgements – citations to individuals who helped you or contributed to your success, or from whom you borrowed information, techniques, or subsections of your design.

The citations for referenced material must be included, using a format as specified by the instructor. (Instructors are often very particular about this.) There needs to be a citation in the text to each of these references at the point where the referenced material is used. It is not enough just to put the source in this list. Include page numbers or equivalent information so that the reader can actually find each citation. Citing a whole book without giving a page number doesn't help the reader find the citation in the source.

Assemble any appendices, things like manufacturer's specification sheets, detailed design calculations that do not need to be in the report, details of simulation results that are not critical to the body of the report, and other less important materials. Be sure each appendix has a callout in the text.

9. Front matter:

Now that the report is essentially complete, it is time to write the Abstract. The abstract is a summary of the entire report. It needs to include a bit of background to explain what was done and what it was to show, enough procedure to explain the process, any particularly relevant piece of data that the reader may wonder about, and a summary of the conclusions. An abstract should usually be between about 100 to 200 words, with no figures, callouts, or citations. It is not formally part of the report proper, so if you number sections, do NOT number the abstract. Often an abstract is in bold type. The abstract may be on the title page, on a page by itself, or before the opening Introduction or Background section. Check any formatting requirements from the instructor.

You may be required to include a title page. If so, there will usually be a required format. Follow it. Usually a laboratory report is too short to need a table of contents. If it has a table of contents, then follow report instructions with respect to format and page numbering.

10. Review:

After writing a report, you should review it. I find that it is better to review a printed copy, so it looks different from what you have been looking at on the computer screen. That makes it easier to notice mistakes and fix them. Look for miss-spelled words, run-on sentences, errors in font (W instead of Ω for example), or other things that may be confusing.

If it is required or allowed, have your lab partner review the report and give feedback. It's often very helpful to have a different pair of eyes look at it. Someone else will notice things that you, as the author, cannot. Do this with enough time to act on the changes before you revise, reprint, and hand it in.

11. Submit:

You're done! Hopefully, you achieve a grade so high that making a resubmission of a revised report later, if allowed or required, will be unnecessary. You want to make the entire laboratory report process as painless as possible, and having a first submission success achieves that, compared to having to reopen this particular exercise for further work.

12. Assess:

Eventually you will get your laboratory report back with a grade on it. At this point the role playing is not completely over. In industry, a report may be bounced back to you if your boss or another reviewer does not consider it fully satisfactory. In that case the immediate problem is to fix it and resubmit. In the school context, you may also be given an opportunity to do the same. Beyond that, you need to look at the report, and the corrections and observations marked, to see what went wrong and what can be improved next time. Errors and mistakes are each an opportunity to learn. The biggest mistake you can make is failure to learn from a mistake.