Writing Laboratory Reports & Journals

220

ENSC 220

Engineering Science Communication Handbook

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1. Journal Based Laboratory Write-Ups

- ✓ **Laboratory Journal**
- ✓ **Lab Write-Up**

MANY ENGINEERING STUDENTS NEED TRAINING in the important skill of keeping complete and retrievable notes. Most immediately, you need to accurately record procedures, techniques, and numerical values obtained during experiments. Brief notes scribbled on loose leaf paper or the backs of envelopes simply will not do– not now and certainly not later when you are practicing engineers. Therefore, ENSC 220 requires journal-based laboratory write-ups not only to help you develop a necessary skill for academic survival, but also to introduce you to the concept of an engineering journal.

Professional engineers use journals to keep accurate records of their work, their meetings and conversations with clients and colleagues, and even their expenses. They can then use their notes to coordinate activities and evaluate progress on team projects, to check the work of other engineers, to verify work performed in the case of legal action, to record when something was invented for patent purposes, to document services performed for accounting purposes, and so on.

Clearly, engineering journals can serve a number of important, professional, legal, and financial purposes, but only if entries are written legibly, if all the necessary information is recorded, if dates can be verified, and if graphic aids are accurately drawn and fully labelled. Of course, these journals are not works of art and may not even be particularly neat. What is important is that notes and numerical values are clearly written and that all necessary information is provided in a logical sequence.

The journal-based approach to laboratory write-ups has two components: a lab journal and a lab write-up. Keep in mind that your journal should contain essentially all of the material needed for your write-up.

1.1. Laboratory Journal

Before you actually sit down to do a lab, you should have already made good use of your lab journal. In doing a pre-lab analysis, you should have identified a number of things worth recording in your journal including, for instance, significant preliminary calculations, tables of expected values, diagrams, and perhaps an outline for how you plan to proceed with the lab. It is always a good idea to have done these theoretical calculations first so that you know what to expect. In addition, you may want to make some preliminary measurements at this stage.

The purpose of doing a pre-lab analysis is to ensure that you understand the theories, tools, and / or models required for a particular laboratory and are fully prepared to begin work on it. Good preparation can dramatically improve your efficiency in the lab, making it more instructive and enjoyable. We, therefore, offer the following questions for you to use as a guide in determining what you need to do to prepare fully for a lab:

- What theories, tools, and models are needed for the parts of this lab?
- What limitations do you expect to encounter in making your measurements?
- What plan of action can you formulate to minimize the amount of time it takes to perform the lab?
- What alternative method can you use if your first plan proves faulty?

Ideally, you are ready to begin a lab when you can do the following:

1. Explain why you are doing the lab.
2. Explain how you will do it.
3. Predict the outcome of putting theory into practice by
    a) anticipating sources of error and uncertainty,
    b) determining reasons why the experiment might fail,
    c) thinking of ways to reduce the bounds of uncertainty.

Because one of the values of keeping a laboratory journal is that it introduces you to the concept of an engineering journal, we suggest that you maintain certain professional standards. You should, for example, adhere to the following:

- Use a book with pre-numbered, non-removable pages. (Although you should use a book with non-removable pages, you may use a spiral-bound notebook on the condition that you number all pages before you begin your journal.)
- Never remove a page from a journal.
- In general, make all entries indelible (i.e., use a pen, *not* a pencil). Never erase or otherwise obliterate an entry. Note, however, that marginal comments about the doubtful quality of entries are appropriate.
- Use glue or tape to permanently insert all graphs or other material produced by a computer or other device.
- Date and, if appropriate, time all data entries.

Use the journal to record your experimental setup and procedure as well as observations made as the laboratory work is performed. If all goes well, your journal will follow the outline you developed from your pre-lab analysis. However, if part way through the lab you discover a serious problem with your preliminary analysis, then you should stop and re-evaluate. If you have a viable alternative already worked out, then employ it; if not, develop one. In either case, be sure to document your revised plan of action in your journal before continuing. Also be sure to note any changes in set-up that appear necessary to obtain the desired results such as, for instance, adding a resistor across some output.

When you record results, be sure to include the error values on all measurements and devices. Express these values in convenient units (i.e., resistor values are typically given as having a 5% error). In tables where all the values have the same error (expressed either as a percentage or as a real value), that number may be placed at the top of the column. In graphs, use error bars to denote the uncertainty (i.e., 4.85 ±.036 mA). See Figure 1 for an example of a table showing the error range.

Table 1: Comparison of Calculated and Measured Results			
V (V)	$I_{Calculated}$ (mA)	$I_{Measured}$ (mA)	Difference (mA)
10±.05	4.85±.036	4.81±.005	0.04±.041
20±.05	9.71±.049	9.63±.005	0.08±.054

Figure 1: Example of Table Showing Error Range

As you work through the lab, ensure that you do the following:

- Keep your proposed plan in mind and record precisely what measurements you are making. Also note any special or unusual methods you are using.
- Think about how the theory relates to the experiments and the measurements you are making.
- If some results do not agree with your predictions, check out why they do not agree and take action to correct the problem.
- Be sure to note sources of error, to rule out any factors which cannot be sources of error, and to give reasons why.
- If an experiment does not work, discover why.

Remember, your journal is an important record of your activities. Record *everything* that you think about, observe, or do not understand about the lab.

1.2. Lab Write-Up

While the length of the lab write-up is, of course, dependent on the size of the lab, assume an ideal length of 1 to 4 pages of single spaced text plus extra for figures and tables. (Please note, however, that you should double-space your write-up if you are printing on both sides of the page.) This document must be written in complete sentences and well-developed paragraphs, following the general conventions of technical and scientific writing, such as introducing all figures and tables before presenting them in the text, using appropriate headings, and so on. Please see Module One of the *Communication Handbook* for further details. Appendix A of this handout provides an example of a journal-based lab write-up.

In general, your lab write-ups will consist of four sections:

- Introduction / Statement of Purpose;
- Method / Theoretical Details and Background;
- Results;
- Discussion / Conclusion.

The introduction should briefly explain the motivation or purpose for doing the lab. In addition, this section should also state whether or not the purpose of the lab was generally met.

Depending upon the nature of the lab, the next section of the lab usually describes the method of the experiment as well as any significant theoretical details and background. Note that in a simple lab, the method may only require a short paragraph to describe it while in a more complex lab, you may find it necessary to include more detail. Point form is often used to detail the method while maintaining conciseness. Typically, this section also includes a simple circuit diagram. You should also describe the theoretical background for the lab including any equations required for illustration.

The next section presents the results obtained. When discussing your results, present the data in graphic form instead of as raw data. Tables and graphs are generally the most effective way to convey this sort of information. Wherever possible, be sure to place calculated and measured values in the same table or plot them on the same graph.

Each table and figure must be introduced in the text before being presented. If possible, all graphs and tables should be integrated with the text rather than being put in an appendix. However, in some instances, your results may be so lengthy and / or detailed that it is preferable to place them in an appendix. Nevertheless, you should still provide a summary of the results in the text. Finally, you should note that in this section you would typically also provide a preliminary interpretation of the results.

The final section discusses the results and draws conclusions as appropriate. In analyzing and discussing your results for a particular part of the lab, you should consider all relevant items from the following list:

- Agreements or discrepancies from expected results and their potential causes;
- Relevant limitations in theories, models, or measurement techniques;
- Alternative methods or solutions;
- Improvisations;
- Changes in plan;
- Problems encountered and how you dealt with them;
- Discussion of your error analysis and of measurement accuracies.

The major point of this section is for you to show your understanding of what has gone on in the lab such as demonstrating that you recognize whether or not a result is within permitted error limits. More specifically, analyzing a lab involves comparing actual behavior to the original theory and deriving an understanding of how and why the real system behaves in ways not predicted by the theory.

Most importantly, note where significant discrepancies between the theory and experimental results occur and note discernible trends in the relationship between the two sets of values. If your explanations rely on your text book, reference books, data sheets, etc., then acknowledge your sources. Where possible, use tables, charts, and graphs to minimize the amount of writing necessary, but not at the expense of clarity or coherence.

As you compare empirical results to your predictions,

- Be honest with yourself about the results. Is the theory consistent with its application? If not, can you explain why not?
- Provide convincing evidence that you have verified what you set out to verify. Can you narrow the margins of error to make the results more convincing?

If after completing the experiment you realize that your results are out of line, then try to locate the source of the problem and, if possible, recalculate results to account for the error.

In addition to discussing the results, this part of the write-up should also show your ability to draw conclusions from what you have done and to articulate what you have learned from doing the experiment. This section is an appropriate place in which to answer the following sorts of questions:

- How would you improve your procedure if you did the lab again?
- Have you learned anything from doing this lab that can help you with future labs?
- Have you gained some insight of general importance?
- What are the practical applications of what you did in this lab?

Keep in mind that you want to draw meaningful conclusions that provide some insight into the ramifications of what you witnessed in the lab.

Appendix A
Sample Lab Write-Up

A good imitation is
the most perfect originality.

Voltaire

Verifying Kirchhoff's Current Law (KCL)

ENSC 220 Sample Lab Report

Pat Smith 9101-10301

For: **Prof. I. M. Smart**

Date: **Jan. 30, 1996**

1.2.1. Purpose

The purpose of this lab is to verify Kirchhoff's Current Law (KCL) by examining a simple current divider circuit. We first analyzed the current divider circuit shown in Figure 1 and calculated the expected currents in each branch. We then constructed the circuit, measured the actual currents, and compared these to our expected results.[1]

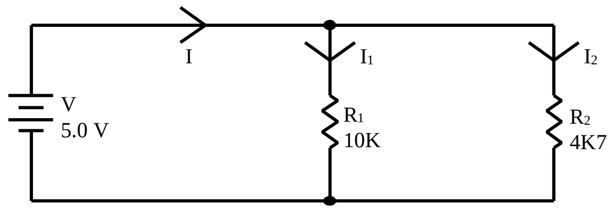

Figure 1: Current Divider Circuit

1.2.2. Results

We can calculate the expected currents by formulating equations for I, I_1, and I_2 using Ohm's Law and KCL. We use actual measured values for the input voltage, V, and resistances, R_1 and R_2, in order to calculate the expected currents. Each of the currents, I, I_1, and I_2, will have an associated margin of uncertainty due to the propagation of resistance and voltage measurement errors through the equations.

The digital multi meter (DMM) accuracy for measuring voltage, resistance, and current is 0.1%+1 digit, 0.2%+1 digit, and 0.3%+1 digit, respectively. The following table shows the resistances used in this circuit as well as the measured input voltage and worst-case minimum and maximum values based on the DMM measurement accuracy.

Table 1: DMM Measurements of Resistance and Voltage

Name	Value	Measurement	Minimum	Maximum
R_1	10.0 kΩ	9.82 kΩ	9.79 kΩ	9.85 kΩ
R_2	4.7 kΩ	4.73 kΩ	4.71 kΩ	4.75 kΩ
V	5.0 V	5.00 V	4.98 V	5.02 V

We calculate the expected values for I, I_1, and I_2 using the following equations:

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I = V \bullet \frac{R_1 + R_2}{R_1 R_2}.$$

Table 2 shows the expected values of these currents as well as their worst-case minimum and maximum values due to the propagation of voltage and resistance measure-

[1] This sample lab report was prepared by Tim Collings, SFU School of Engineering Science.

ment errors through the equations. We can calculate the worst-case minimum and maximum values for each current simply by examining each equation and substituting worst-case minimum or maximum possible measurements for the voltage and resistances as appropriate.

For example, the minimum possible value for I_2 is obtained when V is minimum and R_2 is maximum.

Table 2: DMM Measurements of Current

Name	Expected Value	Minimum	Maximum
I_1	0.509 mA	0.506 mA	0.513 mA
I_2	1.057 mA	1.048 mA	1.066 mA
I	1.566 mA	1.554 mA	1.579 mA

The circuit was constructed as shown in Figure 1, and the currents were measured. Calculations were also done to determine the worst-case minimum and maximum measurements based on the DMM accuracy (0.3%+1 digit for current measurements). These results are shown in Table 3 along with the expected minimum and maximum values (measurements in mA).

Table 3: Comparison of Measured vs. Expected Currents

Name	Measured	Measured Minimum	Measured Maximum	Expected Minimum	Expected Maximum
I_1	0.504	0.501	0.507	0.506	0.513
I_2	1.035	1.031	1.039	1.048	1.066
I	1.518	1.512	1.524	1.554	1.579

With the exception of I_1, none of the measured current ranges falls within the acceptable range of expected values.

This error occurs because the DMM current measurement process introduces a systematic error caused by its internal shunt resistor being placed in series with the current being measured. This shunt resistance has the effect of decreasing the actual measurement below the expected value. We can eliminate the effect of this shunt resistor by including the effect in the equations used to calculate the expected current values. The shunt resistor, R_s, has a value of 100 ohms on the 2 mA range used in this experiment. If we replace R_1 with R_1+R_s and R_2 with R_2+R_s and use these values in our equations, then our expected results are almost exactly the same as those measured. Table 4 shows the results when R_s is included in the calculations.

Table 4: Measured vs. Expected Currents (R_s Included in Calculations)

Name	New Expected	Measured Minimum	Measured Maximum	Expected Minimum	Expected Maximum
I_1	0.504	0.501	0.507	0.500	0.508
I_2	1.035	1.031	1.039	1.030	1.040
I	1.518	1.512	1.524	1.510	1.526

These new calculations modify the range of expected currents so that the actual measurement ranges fall within these acceptable bounds. Therefore, we can truly say that the measurements are valid within the bounds of uncertainty. Note, however, that I^1 I_1+I_2 (even if we use minimum values for I_1 and I_2, along with the maximum value for I) so we haven't actually verified KCL.

1.2.3. Summary and Discussion

This experiment illustrated the importance of performing proper error analysis. We were unable to verify KCL because when we measured currents in the circuit, we were changing the actual circuit. A discrepancy arose in our experiment when measuring the currents in each branch. We made sense of these results by including the effects of the shunt resistor, R_s, in our calculations (a systematic error). Alternatively, we could have chosen to "correct" our measurements by "nullifying" the effect of R_s and then comparing our "corrected" measurements with our original expected results. This technique would allow us to verify KCL and we will derive and use this technique in future experiments.

The objective of this lab was to verify KCL. Having discovered my source of error (the shunt resistor), I should develop an alternative strategy—one that will account for the shunt resistor in my circuit and calculations. I suggest placing an additional 100 Ω resistor in *each* branch to represent the shunt resistor. I would then remove the 100 Ω resistor from the appropriate branch when measuring the branch current. By doing this, I don't really alter the circuit at all, and my results should be consistent. I am simply replacing the shunt resistor of the DMM with another "dummy" resistor. My calcula-tions for expected results should reflect the addition of these extra "dummy" resistors, and my results should show $I=I_1+I_2$.

I went into the lab to try this and it works. If I was unable to do this, then I could not verify KCL (which is the main objective of the lab); consequently, I would have no confidence that the "theory" works in practice.