Appendix A

How to prepare a good lab report

General considerations for lab reports

The key to success is to treat laboratories like mini research projects. A typical research project begins with a question that one wishes to answer. An experiment is designed to gather data that can be used to test various hypotheses that explain the observed behaviour or to test the validity of the claims made by some already established theory. In this process, the documenting of every detail of the experimental process is of paramount importance since the validity of the scientific method requires that, given the same experimental conditions, anyone else should be able to reproduce these results.

There are two parts to any research project. A planning stage that works out in detail the task to be performed and describes the measurements to be made and the way they will be recorded. If the intention is to validate a theory, the pertinent elements of the theory to be tested should be reviewed prior to starting the experiment itself.

The second part consists of performing the actual experimental procedures that will provide the required data to analyse. From this data and analysis, some conclusions can be reached regarding the original question.

A good lab report should contain all of the above elements. Treat these labs as your personal research projects. In this course, the labs are designed to support the lecture material, and each lab has certain specific task(s) for you to perform, so you can develop the real-life feel for the abstract theoretical concepts you are learning, but the laboratory skills you develop will be useful in later, more independent research work. Here's the outline of how you should proceed with this two-step process:

Pre-lab should be completed before the actual lab session. Set up a LaTeX template with:

- a short introductory statement of purpose;
- an outline of the methods that you intend to use to satisfy the above, i.e. the experimental parameters to be measured;
- headings that separate each exercise, if more than one;
- space for drawings, pictures, data tables and graphs to be included.

In-lab tasks completed during the lab session will include:

- this template is used as a guide to the tasks to be performed;
- the data tables are filled and graphs are generated and inserted as planned;
- some conclusions are drawn from your experimental results.
- A short summary of your personal experience, describing any noteworthy observations, insights and possible issues encountered that would be meaningful to yourself or someone else repeating the experiment complete the lab report.

You can now review your lab report to make minor additions and corrections to the format and content, before submitting the final version for review. Below you will find a sample template that could be used for Lab.1: Data Analysis.

Your lab report submissions should be concise, comprehensive and include error estimates for all measured and derived quantities, properly rounded, without which your results will be meaningless. Your original data, graphs and other pertinent content should be saved and readily available should you or someone else wish to review it.

A.1 Before the experiment

A document structure can be coded in Overleaf prior to the lab session that contains the overall framework of the future lab report: title, author (you), sections and subsections, room for the Appendix with raw data, *etc.* Several sections should be already written, with only minor changes expected during the final pre-submission review. These should contain a brief plan for the experiment with citations likely of this lab manual and of the lecture notes and textbook (Introduction); a brief but sufficient theoretical summary so that you do not have to look for the form of the fit function you are planning to use to analyse the data (this may be a separate Theory section, or considered a part of the Introduction), and an empty table for where the data is going to be added (Results). If the data is brief, this table (or tables if there are several stages to the planned experiment) can be entered directly, or they can be saved in a separate data file to be included in an Appendix later.

For example, our first experiment is focusing on learning the data analysis tools, and the basics of statistical analysis of the data, which is provided. If it were a regular experimental lab, it might have the title of *Investigating factors controlling the motion of a pendulum* and before you arrive in the lab it migh look something like Figure A.1. What is not shown in Figure A.1 are additional sections than may be appropriate to have prepared in advance: the text of a macro that will read in the data file and plot it, then perform some statistical analysis; or perhaps your responses to theoretical or computational exercise that you are expected to complete before the lab. The macros are likely to be included in the Appendix of the final report, while the required exercises could occupy their own sections, or be embedded in either the theoretical introductory sections or be a part of the Results. Most likely, a figure or two is expected to be needed to show the data in Results or to illustrate your Conclusions; empty placeholders for such figures could already be there.

It is perhaps surprising that so much of the "final product" — the lab report — can and should be prepared in advance of the lab itself, but if you adopt this approach you will find that your lab preparedness will increase dramatically, and you will feel much more confident coming into the lab and dealing with the experimental apparatus. Also, the amount of your post-lab work will decrease; after all, all these sections have to be prepared at some point, and coming out of the lab you will already have done so, with only the Conclusions and a quick overall editorial review remaining.

A.2 During the experiment

With the pre-lab preparation completed, what needs to be done in-lab will be streamlined. Make sure all items on this checklist are completed before leaving the lab:

- fill in the tables with measured and calculated data; include measurement error estimates;
- insert graphs as planned, with captions and scaled to focus on the region of interest;
- save graphs and the macros that generate them;
- document observations and describe how the data was obtained and analysed;
- compare experimental and theoretical results;

Introduction

A pendulum consisting of a ball hanging from a string of length L is set to swing and the period of motion T is determined using a photogate. The period is measured as the time between every *two* beam interruptions caused by the passage of the string. From dimensional considerations, it is expected that L and g are the only variable affecting the period T, $T \propto \sqrt{L/g}$, so the experiment is repeated for balls of various masses to verify that the results do not depend on mass.

Statistical analysis of experimental errors

Given a sample of N values, the average values $\langle L \rangle$ and $\langle T \rangle$ are defined as

$$\langle L \rangle = \frac{1}{N} \sum_{i=1}^{N} L_i \,, \qquad \langle T \rangle = \frac{1}{N} \sum_{i=1}^{N} T_i \,.$$

Assuming small-amplitude pendulum oscillations, with the small-angle approximation $sin\theta \approx \theta$, it is expected that

$$g = 4\pi^2 \, \frac{\langle L \rangle}{\langle T \rangle^2}$$

and, therefore, a precise measurement of local value of the acceleration due to gravity can be conveniently obtained using a very simple apparatus.

Here you can also include answers to questions that can be completed before the lab session:

- for the given L and T data sets, the scale errors are ...
- to prove that an average deviation is zero ...
- to confirm this numerically for L and T ...
- to derive and evaluate dg/dL and dg/dT ...

Results

Over several trials, a series of T and L values were recorded and are reproduced in the following table:

Trial #	$L \pm 0.05$, cm	$T \pm 0.01$, s	$m \pm 0.1$, g
1	88.90	1.88	25.0
2	88.88	1.86	25.0
3	...	...	...

Figure A.1: An example of what should be in a lab report document prepared before coming to the lab. The imagined experiment might be *Investigating factors controlling the motion of a pendulum.*

- include some concluding remarks, description of any issues, it etc.

A.3 After the experiment

If you have not done so during the lab, now is the time to:

- add concluding remarks and reflections;
- revise and improve the appearance of figures if necessary, to ensure legibility of all text labels, size of plotting symbols, use of colour, *etc.*;
- if you used `\include{ }` or `\insert{ }` commands to embed the text of your macros in an Appendix, ensure that the latest versions of figures and macros are uploaded to overleaf;
- review the entire lab report for any typos or errors, then submit.

It is by design that the after-the-experiment section is so short. You are done, and ready to start preparing for the next week's laboratory. You may want to start by making a copy of the current or previous lab report: after all, while the content of sections may be different, the new lab report will have roughly the same structure, the same basic organization of Introduction, Results, Conclusions, Appendix, *etc.*