Chapter 6 What to Do If Things Don't Work

Overview:

There is a common misconception among undergraduate students that Laboratory Reports are always supposed to come out "Right." Any unusual or even unexpected behavior is an error on the part of the student, to be obscured or covered up in the interest of achieving a better grade. This point of view assumes that the primary purpose of laboratory work is student assessment: putting a grade on the student. Generally, though, that is not the case. Indeed, the purpose of grading may be more to motivate the student to take the exercise seriously: plan and perform the exercise and write the report afterwards. Without grading that might not happen.

Graded work generally serves three purposes. It is indeed used for assessing the student, the most obvious purpose. But it is also used by the instructor to get a sense of how well the class as a whole, or even particular students, understand the material, so that future instruction can be modified to include review or additional coverage as needed. Perhaps the most important function of laboratory exercises is that the experience should deepen the student's understanding of the subject, in a way that abstract study cannot. The exercise of formally writing about what happened is part of that experience, in that articulating in language the principles , observations, and conclusions is an important part of the learning process.

The most important contributor toward student learning from a laboratory exercise is how the student understands his role. Possibilities include:

1. The student is just a data taker. Someone else designed the laboratory exercise and prescribed a procedure to be followed, and perhaps even arranged for the apparatus to be set up and provided a form for recording data. So, the student's job is merely to fill in the data, and generate a report following a format provided. In this understanding, the key issue is whether the data was recorded correctly. If the answers come out "wrong," the student supposes it is his fault. Maybe the data taking instruments were not used correctly, or the numbers recorded incorrectly. If the assumption is made that this is a test to generate a grade, then obscuring the error may seem a reasonable approach to mitigate the damage. The problem, though, is that usually the student is expected to be more than a data taker; he should be thinking about the exercise, and why something may not have come out as expected. Too often this is the way students approach a laboratory exercise.
2. The student as direction follower. In this mode of thinking, the student goes a step beyond being just a data taker; he also has to correctly set up the apparatus, perhaps even choose components, or even design a system which is to be characterized. So, the student focuses on procedure. If things don't work, then something must have been done wrong, and the procedure was in error. A student who sees the laboratory exercise merely as a test of instruction following and data recording skills will likely see surprises in the results as his fault and may seek to cover up evidence of his errors, as above.

3. The student as investigator. This way of approaching the exercise sees the student as trying to fully comprehend what happens in the laboratory. The exercise in not just a test of direction following and data taking, but also of understanding what has happened. So, if things do not go "Right" in a laboratory exercise, that means an expanded opportunity to learn. What actually happened? How can one find out? A laboratory exercise that does not go as expected, to be understood, requires deductive and other reasoning processes that more fully require and demonstrate a true understanding of the physical phenomena at play. This is the perspective that will help you get the most out of a laboratory exercise, especially one that "goes wrong."

The remainder of this chapter explores ways and reasons a laboratory exercise may seem to "go wrong", and what the student can reasonably do in such circumstances. This chapter is necessarily rather general about these things. A specific exercise and issues that arise is described in Appendix G.

General Principle: A Professional Perspective:

The most important issue in dealing with adverse laboratory results is to maintain a professional perspective. Engineering is a profession. That means that the engineer is providing a useful service based on a specialized understanding of some domain. In the case of engineering, that domain is the operation of physical systems based on the sciences and mathematics. Generally, the product of an engineer is useful and actionable information. One form of that information is drawings and similar documentation that is passed on to the manufacturing phase of product development. But more often, an engineer is furnishing information to a client, or someone in management, who needs to make an important decision based on that information.

A laboratory report is a reasonable educational surrogate for such real-world reports. In science classes, experiments are conducted to either confirm or deny the truth of some hypothesis or proposition, such as whether a real-world phenomenon follows the predictions made in accordance with a certain theory. In industry, a comparable study might be intended, for example, to show whether a particular sensor would be effective in the real world. It is important to discover whether the concept proposed is worth pursuing by investing more money to develop a prototype, or whether the approach should be discarded in favor of some alternate approach. The issue is important financially, since money spent developing the proposed approach is lost if it turns out not to be viable later. It is important temporally, in that time spent on development is also lost if the approach turns out not to be viable. That is especially important in that a competing firm may also be developing a product to address the same real-world problem, and the first to market will likely have an immense advantage.

The most important quality a professional brings to his client is understanding of the truth. That truth may need to be articulated in a way that a non-technical client or manager, or client or manager with less specialized knowledge, can understand. That is why the writing of reports is so important. So, in your reports, the primary imperative is to be truthful and forthright. Your information, whether for good or bad, is important, and will likely influence your organizations future in important ways. A report that something does not work is every bit as important as confirming that something does work. If you do not have enough information to give a definitive conclusion, it is important to convey that too. You don't want the company's future to depend on your guess.

In a laboratory report you need to be modeling this perspective. You need to clearly describe what was done and the data recorded, so that if there is a mistake later in analysis and conclusions, somebody will be able to find it and prevent action being taken on a wrong conclusion reached in error. If data does not support the hypothesis, or if performance of the system does not meet specifications or expectations, that is important information. You don't want your organization to invest resources in an approach that later fails. To summarize the attributes your report should employ:

1. Be truthful and forthright.
2. Clearly describe your procedure and results so that other people can check them.
3. Show clearly your analysis and how you reached your conclusions.
4. If things don't work as expected, draw on theory and your knowledge of the system to identify what went wrong, if possible, or hypotheses about what went wrong if a conclusion is not possible.

The quality of a report is most important in precisely the case where the outcome of the exercise is unexpected. In the business or government context, this is likely to precipitate a stressful situation. Your boss will be unhappy to hear that his preferred solution is not going to work. He may not even want to hear the bad news. You may be labeled a troublemaker or worse. But, the duty of an engineer is to speak the truth, even if that truth is unwelcome. Ultimately the truth will be known, and the issue is how much expense and unpleasantness is precipitated when it does. Sooner is usually better.

What can go Wrong?

So, here we turn to the specifics of why a laboratory exercise may "go wrong." What we are dealing with at this point is diagnostics, sometimes called "debugging" when it comes to finding and fixing system problems that cause wrong behavior. This, in general form, is a list of hypotheses. The report writer needs to consider these and perhaps other hypotheses, considering and testing each one.

1 The hypothesis of the experiment is indeed wrong.

In a science class this seems unlikely, especially if the hypothesis is the validity of a scientific principle of long standing, such as Newton's F=ma or Ohm's V=IR. Would your instructor throw you a "ringer" by giving you a "law" to prove that isn't actually valid? Look at your data. Does it say that the hypothesis is true, or not? It is your professional obligation to report what you see, and how you came to that conclusion. The worst thing you can do is see data that seems to disprove the hypothesis, and then say that you conclude the hypothesis is true. No; even worse would be to fabricate data that you did not take that would support the hypothesis, in order to obscure your observations! That is lying, and in a professional context is criminal.

2 The hypothesis is not applicable for the experiment as performed.

This possibility is not quite as surprising as the one above, but will look like it. The hypothesis or "law" to be proven actually is valid, but the apparatus or test doesn't actually fulfil the requirements of the hypothesis. For example, Ohm's law is tested to see if V=IR using an incandescent light bulb for the resistor. R is measured using an accurate laboratory grade meter. But the laboratory results fail to show a constant ratio of V to I. In this case, the problem is that the component measured, the light bulb, does not have a constant value of R independent of temperature, which in turn is affected directly by V and I. Ohm's Law is NOT true for a light bulb! Similarly, a rocket with fixed thrust (force) will not have a constant acceleration because mass is changing. When a hypothesis seems to fail, very likely some assumption has been made that turns out not to be true. If it was your lab instructor who specified the component, might he have slipped in something that would behave this way? (The answer is often, "Yes!")

3 The measurement means are not adequate to reflect the real-world situation.

In this case, perhaps not initially distinguishable from those above, the issue turns out to be the instrument used to make a measurement. No instrument is perfect, and some affect the system simply by making a measurement. For example, inexpensive digital Voltmeter has an input impedance of 1MΩ. Measuring Voltage in a circuit made up of MΩ Ohm magnitude resistors actually changes the circuit, so that readings with the meter present are different from the actual Voltages with the meter absent. In like manner, the pressure gauge on an air pump, when attached to a bicycle tire, may not indicate the original pressure, because air was drained to pressurize the connecting hose. Beware of instrument assumptions. Even laboratory grade instruments have their limitations. For example, many typical laboratory AC Voltmeters are not designed to measure high frequencies, they will be wrong if the frequency is well into the KHz region or beyond. There are frequency limits on other instruments as well.

4 A component does not have behavior corresponding to its specification.

This situation occurs quite often. A component may appear to be perfectly normal, but behave in a faulty manner. One potential reason is that it is, in fact, faulty. A transistor may have been subject to excess dissipation, and has failed. Some of the never-used resistors found in lab stocks, which have been there for several decades, have been found to be off by more than 50% when the specified tolerance is only 10%. (A 75 Ohm resistor from the SLC238 stocks was found, after considerable debugging effort, to actually be 130Ω! It was right out of the cardboard sleeve, never before used.) Another potential reason for problematic behavior is a connection error: a terminal is not connected correctly, or the terminals are corrected wrong. A backwards diode will not operate properly. A transistor connected backwards may even behave like a transistor, but of inferior quality. This problem is very common.

5 An error was made in following the procedure or in component selection.

This is perhaps the seeming most likely problem, and indeed is well worth checking. If there is a way to test individual components to see if they are what they should be, do so. For example, it is very easy to look at a resistor marked brown-red-black and mistake it for one marked brown-black-red. (I've made that mistake more than once!) An Ohm meter will reveal this error. It is easy to mistake one transistor type for another, or plug something into the wrong hole on a solderless breadboard, or to make a measurement error when reading a ruler while positioning something. Aside from looking at the components and experimental configuration searching for errors, the system can be tested in parts. For example, in an electrical system, where three resistors meet, do the currents calculated for all of them sum to zero as Kirchoff's Law says they should? (Or, does some additional current leak out through a capacitor connected backwards?) Do forces sum at a junction? Do displacements around a mechanical loop sum to zero? Construct and test hypotheses about your system, looking for discrepancies that will give clues where the problem may lie.

6 The expectations used to predict may not take real-world conditions into account.

One of the reasons for doing work in the laboratory is to acquaint students with the difference between models and reality. We as engineers construct abstract models of reality and use those models to predict behavior. For example, we use F= -k x to characterize a spring: force is proportional and opposite to how we stretch the spring. This linear relationship is mathematically convenient, but real springs bottom out, can break if stretched too far, or may be nonlinear even close to equilibrium. The wires that connect a power supply to a circuit are actually inductors. Capacitance and friction are everywhere. Non-ideal behavior is widespread in the real world, including the laboratory. The issue is, does it matter? Part of engineering laboratory exercises is learning to recognize where real-world deviations from our models matter, and what to do when that occurs.

7 The data are actually correct, but a mistake has been made in calculation.

This is not an uncommon problem. Sometimes the error is a faulty calculation that, in hindsight, seems obvious. At other times the error is more subtle. An example is using quantities that are actually complex, like capacitor Voltage in an AC circuit, and treating it mathematically as if it is real without considering the phase. In a case like this your conclusions may be wrong, or you may not be able to reach conclusions, but can point out that an error (so far unidentified) must be present. A reviewer may well be able to find the error, and can then reach valid conclusions working from the raw data you have supplied.

So, What Can You Do About It?

At this point, we assume that the data is taken, and the time available in the laboratory is at an end. You have been analyzing your data and writing your report, and you suddenly realize that things are not coming out right; something is wrong.

The first (and obvious) thing to do is try to figure out what went wrong. Consider the various possibilities in the preceding section. Construct hypotheses, and test them, using theory and your knowledge of the system and the data you collected. Can you find a hypothesis that is both reasonable and consistent with your data? If so, good! That means your report needs to include, after giving your raw data, an analysis section or subsection that shows how you determined that there was a problem, your hypothesis about what went wrong, how you tested your hypothesis, and your conclusion that, yes, this is what went wrong. If it is possible to reconstruct what should have happened from the data you took and go on to successfully reach the conclusions expected of the laboratory exercise, go ahead and do so. Very likely you will be left unable to draw conclusions for lack of valid data. In that case, it is important to state in your conclusions section that a conclusion could not be reached. (You may go on to make a recommendation how the problem that prevented successful conclusion can be avoided in the future.)

Unfortunately, a more frequent situation is that the student has bad data or bad conclusions after performing analysis, but does not know why. In that case, it is important to convey to the reader as much information as you can so that the reviewer may be able to reach conclusions, at least concerning what went wrong. In the business world, the reviewer is likely to be a more senior engineer whose job it is to help in exactly this kind of situation, where someone more junior needs help. So, in addition to your raw data, you need to list each of the hypotheses you considered that might explain what went wrong, and give the procedure and data collected in attempting to test each one. If resources permit, you can also model possible failure hypotheses using abstract principles or simulation, to show how the system would behave for each of the faults hypothesized, and how that would or would not be consistent with observations. This kind of analysis can become lengthy, and there is a practical limit on the resources of time and effort you can afford to put into a laboratory report. But, you should do enough to show that you made an earnest effort.

Ultimately, your professional duty is to convey as accurately as possible what has happened, and give as much information as you can about what the possibilities are and any further data that might help someone else understand the situation.

After turning in a report which states that, "Something went Wrong," it becomes someone else's responsibility what to do about it. In the business world, that's a management issue. In response to such a report from a junior engineer who has put forth a conscientious effort, the response will likely be, "This guy needs help. We'll give it to him." With that help, you are able to solve the problem. Or, it may be that the problem turns out to be badly posed, too difficult, or downright unsolvable. That becomes a problem for a more senior engineer. By giving a forthright and honest report, you have done your duty.

In the academic environment, the report gets graded. But, undoubtedly, your instructor will be wondering, "What really happened?" You may be given some guidance and asked to repeat the exercise. It may be that your instructor can identify what happened, especially if you have been generous in providing helpful information. That's good! If you do not come away with satisfaction, stay curious. Maybe the next semester, or years later, you will look back and, all of a sudden, say, "Aha!" That's when you will have learned the most, more than if nothing had ever gone wrong.