Preface

(Please read before the first meeting of your lab section.)

The most important goals of these labs are to;

- Give you a chance to construct knowledge[1] yourself (rather than getting it from some authoritative source)
    - Let you think critically & practice your reasoning skills[2]
- Learn to build scientific models[3] (by actually constructing one)

and of lesser importance;

- Use the model of electricity that was found to investigate RC circuits
- Learn to use multimeters

The starting-point is observations made in PHYS 2126 labs of things that actually happen. You will have to pay particular attention to your actual observations because the model of electricity that you construct will be based on them.

What are scientific models?
Models are arrangements of fundamental ideas that explain physical phenomena. The fundamental ideas in the model must be suggested by physical observation. The model must have some predictive power.

I want you to do more than use a model that someone else made. I want you have a hand in coming up with a model. You will do this by making observations and thinking about their significance in relation to other observations that you have made.

An example of a model that you have encountered in physics I is Newtonian mechanics. It probably wasn't presented as a model in your class but is a model nonetheless. It contains three laws that are suggested by observations. (Newton's three laws are the 'fundamental[4] ideas' that are part of any scientific model.) It is an extremely successful model in that Newton's model explains the motion of objects in many circumstances.

Models are built by asking ourselves questions & suggesting tentative answers (often called hypotheses). The hypothesis is scientific if it is subject to comparison with physical reality. (While it may be interesting, any non-testable hypothesis is outside the realm of natural science.) There

1 Those that have read the recommendations of the American Association of Physics Teachers will recognize that this goal "captures some of the overarching goals of the undergraduate lab curriculum". (From http://www.aapt.org/Resources/upload/LabGuidlinesDocument_EBendorsed_nov10.pdf)
2 For those of you that anticipate doing the MCAT exam, "Reasoning" is regarded as particularly important among the "Scientific Inquiry and Reasoning" skills given in the AAMC document https://www.aamc.org/students/download/374012/data/mcat2015-cp.pdf
3 This goal is mentioned in the AAPT document that is mentioned in footnote 1.
4 Remember that 'fundamental' doesn't mean 'easy'!

must at least be approximate agreement between physical reality and predictions made using the hypothesis if we are to accept it as not being false.

Why/How do we practice reasoning and critical thinking skills?
Even if you don’t usually think about scientific models, you will still need to think critically about the information that you encounter. You practice critical thinking when you put things together for yourself rather than just going along with conclusions made by other people. (Even though you might set out to reach your own conclusions, you might end up agreeing with the conclusions of other people.)

Critical thinking is easier if you ***make observations yourself*** because you’ll know exactly what happened etc. (I try to avoid indirect ‘observation’ where you have to take my word for it that a certain result/observation is what happens. In this manual, ‘observation’ always means ‘direct observation’.) ***I hope that you don’t think that I am underestimating your abilities when observations are simple***. I’m not. I just want you to be thorough and to be sure of the fundamental observations before your use them to make conclusions. Even though the observations might be simple, it is not easy to use them to make conclusions that help us construct a model.

Implications:

The goals chosen have certain implications.

- *Lab Apparatus must be simple*. This reduces the time needed to figure how any particular measuring device works. Needlessly complicated equipment just puts you in the position of taking the word of someone else that the equipment operates as you are told. Needless complexity makes it very hard to think critically

- *Lab reports have a simple structure*: *in this lab, reports involve writing answers to questions*. Questions on lab reports often involve ‘pulling together’ several observations so that a useful idea is seen more clearly. The simple structure is intended *to give you time to think critically* and think about the significance of your observations

- We’ll concentrate on *systems* (electrostatics & DC circuits) *in which a small number of fundamental ideas is enough to make a model* that can explain your observations. These systems also have the advantage that it is possible for us to make all the necessary observations with the simple apparatus that we’ll use

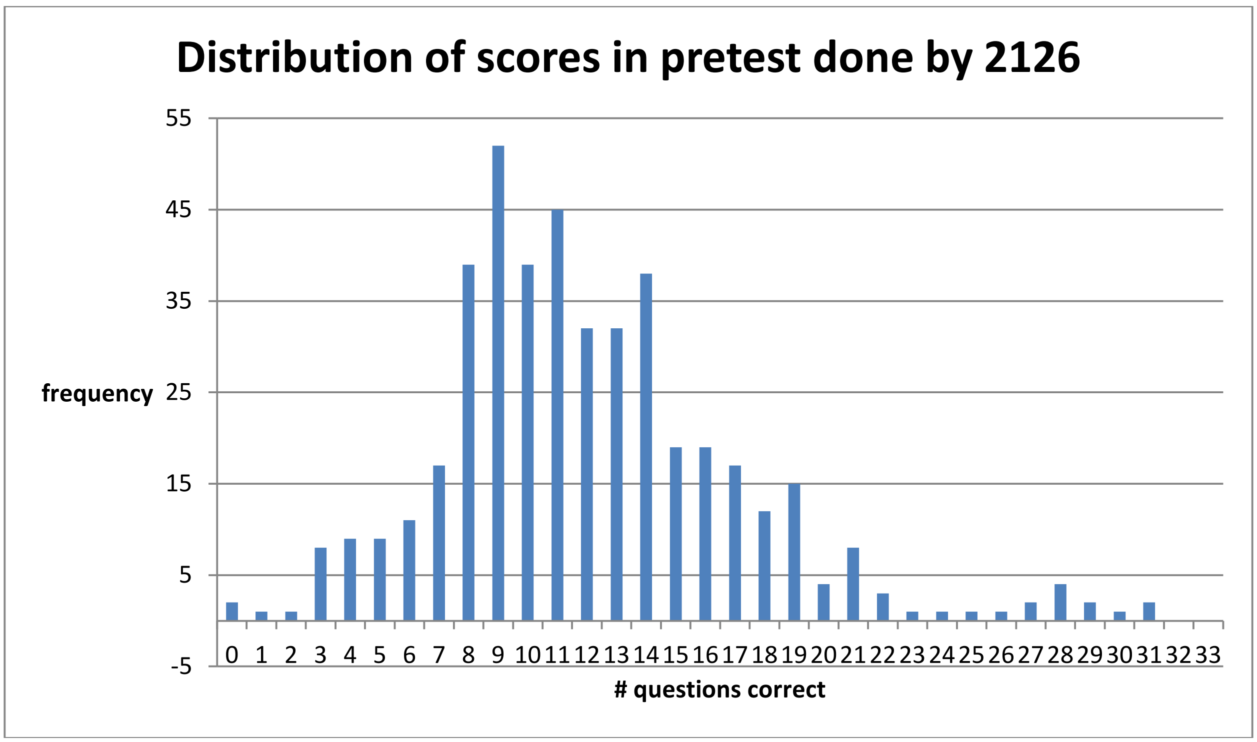
- *‘Covering’ new material is not a very important goal in these labs*. Actually, the involvement of lots of unfamiliar material makes it difficult to think critically and to build models

If we restrict ourselves to observations that we have made then **some familiar terminology will be out of our reach**. Good examples are the terms; **‘electrons’, ‘protons’ and ‘neutrons**’. Observations come before any terminology that explains the observations. Since we won’t be directly observing these fundamental particles in this lab, you won’t need to use these terms. ***Put these terms aside when you need to explain an observation in this course***. From another perspective, not using these terms won't hinder your explanation of anything that you'll see in these labs. (Of course, all your conclusions will be consistent with electrons, protons and neutrons when you want to explain these 'microscopic' observations later.)

Another difficulty with terminology occurs when we observe electric circuits. All of us have heard of voltage, current and resistance though the meaning of these terms may not be totally clear. The root of this difficulty is probably that you haven't observed circuits directly yourself. Part of the solution involves not using ***the terms voltage, current and resistance to explain anything in these labs***. As above, it will be difficult for most of us to avoid using familiar terminology when trying to describe DC circuits.

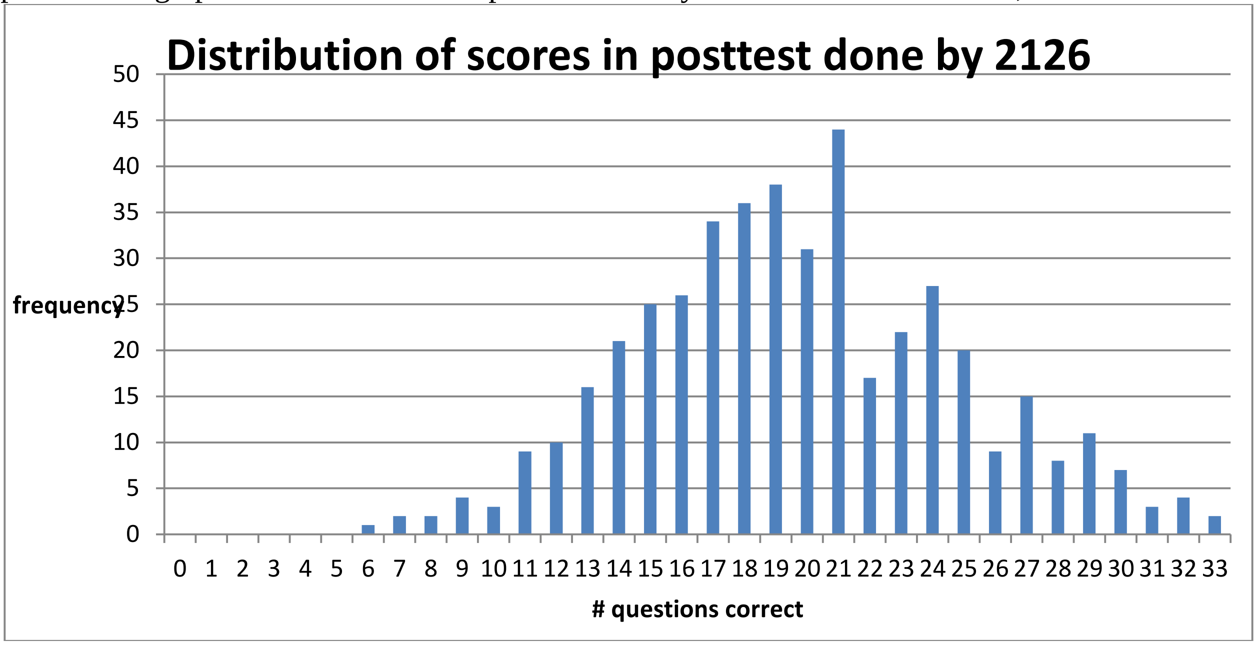
But should we? **Students often ask me why they can't use concepts (such as voltage, current and resistance) that they are already familiar with. The answer is simple: it is frequently the case that the student is familiar with the terminology but doesn't really know much about the underlying concept**. The only way around this is to build the concept yourself from 'scratch'.

Few students have asked me to justify this claim but (true to the spirit of the course) I use observations that I have made myself. Here is a graph of the number of students (the frequency on the y-axis) that get a given number of questions correct in the pretest.



The first thing that you should notice is that the average number of questions answered correctly is about 12 out of 33. (The average is 36.7% $\pm$ 0.7% if you want to work it out.) If someone really is familiar with the concepts behind DC circuits then it is quite possible to get all of the questions right. However, only 15 students out of the 447 got more than 22 questions right. The fact that only 15/447 = 3.35% got more than 66% does not suggest mastery of the underlying concepts. (In case you are worried that this data sample is a statistical fluke then I invite you to look at pretest data from other semesters [posted on the bulletin board outside SLC 1.211] and see how similar the grade distribution is in these other cases.) ***Be careful; familiarity with terminology is not the same as familiarity with the underlying concepts***.

I don't like pointing out a problem unless I know of a solution. This course can address the problem. A graph of the results in the posttest done by the same 447 students is;



The average is much higher: 60.0% ± 0.7% (almost 20 questions correct) with almost half getting 20 or more questions right. (Nobody got fewer than 6 questions right.)

This won't be enough. You'll be refining ideas that underlie these terms as you develop a model of electricity. Unfortunately, half-understood ideas about voltage, current and resistance delay your understanding. Using them puts you in the awkward position of not knowing if what you suspect is actually true or if the problem is with partly understood terminology. It is very easy to confuse a fundamental idea with a piece of technical terminology that is often used to describe the fundamental idea. ***A practical solution is to leave those terms aside and temporarily develop a set of 'home-made' terms ourselves***. (I'll help through suggestions and instructions in the manual.) This will put enough 'distance' between the familiar terms and your understanding in order for a better understanding to develop unhindered. After we are sure of our understanding, it will be easy to exchange our terms for the more usual ones. Since you'll have been involved in defining our 'home-made' terms from the beginning, you'll know exactly what they mean. We'll use these 'home-made' terms until we do the lab called Multimeters.

Practicalities

You will do a quiz about DC circuits at your first lab meeting. This quiz contributes to your course grade. (See course policy #2 for details.) The quiz gives you the opportunity to tell us about your initial understanding of DC circuits and will involve the usual terms of voltage, current &

resistance. The test is about batteries and the brightness of one bulb in a circuit compared with the brightness of other bulbs.

A feature this ***multiple-choice quiz*** is an ***option that allows you not to choose an answe***r but shows that you thought about the question and took the quiz seriously. The idea is not to force you to choose when you haven't seen the topic of the question or are genuinely unsure of the answer. Of course you can use anything that you know and any convictions about how circuits actually work. ***If you can't reason your way to an answer after considering the question for a minute or so, then choose option (k) instead of making a random guess*** at the answer. ***Don't spend time trying to eliminate answers that you think 'must be wrong' and guessing*** among the ones you find most plausible.

Even though these topics have technically been 'covered' in your previous courses, the reality is that the average student doesn't do particularly well with this pretest. I choose to take this result seriously and use a large fraction of the course to give you the opportunity to do something about this. Please take the opportunity.

In the past, I have found it to be useful to return right to the beginning of DC circuits and to take as little as possible for granted. Rather than tell you (again) how DC circuits work, I invite you to put things together for yourself. ***Please have patience with yourself: it is not easy to put ideas together if you haven't had to do this before.*** (This is just as true if the subject matter is dismissed as being 'simple'). I hope that learning the skill in this context will help you to put ideas together in other contexts later.

Make good use of ***office hours***. A quick ***question asked early*** is often all that is needed to make progress on a Pre-lab. By all means, tell me or your TA if you don't understand something. However, ***complete answers to questions are not helpful unless you have grappled with the questions yourself***. Expect any of us to ask you what you think (and why) before saying much more.

Expect something similar during the labs: ***expect TAs to ask you questions about what you are thinking or doing***. Their questions are intended to *encourage you to think about things* in useful ways while leaving the implications and conclusion to you! During the lab, the TA may also ask any person to explain something or repeat any part of the procedure if they feel it might be helpful.

My TAs do almost all of the face-to-face instruction in these labs. Several of the lab sections will meet during my other classes and office hours for those other classes. Lab sections also meet during my other activities for the department; faculty meetings etc. I may pop-in for a few minutes when I can but that is all I expect to have time to do.

Beware of blindly following instructions in the manual. ***You are not being asked to follow a recipe so don't expect my instructions to be a detailed list of directions. Expect to have to read ahead and think about my instructions before doing anything.***

If a question asks you to explain something then an answer of "yes/no" or "I can't explain" is not sufficient. Don't move on until you find explanations for things. Please write neat answers for your TA. This should be easy for questions that involve simple observations or data items. ***For more complicated questions, consider writing your first answer on another piece of paper. Only write your answer on the Report that you'll give the TA after you have thought about your 'draft' answer and are sure that it answers the question that was asked***.

Does this approach work?

Yes. You will do another quiz towards the end of the course. (As with the first one, this quiz also contributes to your course grade. See course policy #2 for details.) Comparison of the two results has indicated significant improvement in every semester. As above, I invite you to compare the pre- and posttest results (posted outside SLC 1.211) so that you can see that there is quite a change. While most students gain significantly from the course, the amount that you gain is totally in your hands and is highly dependent on the thinking that you do to develop your understanding.

Format of Questions for Lab Reports.

I mentioned earlier that the format was simple in PHYS 2126: you write *answers to questions*. These questions are designed to lead you through the thought process that I'd lead you through if we were talking to each other. Some questions are about observations that you have made and are not difficult. However the function of these questions is to remind you of something helpful just before I ask a more difficult question. This is the reason that marks offered for different questions vary so much.

I don't want to put words in your mouth while leading you through a "thought process". In many instances I could be more specific I one question but only at the cost of telling you the answer to a later question. This puts some limitations of the specificity of my questions.

The requirement that you learn actively means that I have to phrase my questions in terms I know that you are familiar with. Of course, it is easier to ask question when we have access to a set of well-defined & physically useful terms. Those terms will often be unavailable since we will be in the process of approaching an understanding of those useful terms!

At the same time, if you find a better way of asking a particular question then please email it to me.