A Fresh Start for Science Labs: Three Springboards to Inquiry

Tim Erickson
Epistemological Engineering
DRAFT! August 2004

As progressive educators, we strive for open-endedness. For example, letting students ask and answer their own questions gives them ownership, and responsibility for the material. The end-of-term project, “investigate a topic of your own choosing” is a good idea, but this often turns into a report about something (e.g., solar cars) rather than a real scientific investigation. Wouldn’t it be great if more students would make hypotheses, decide what to measure, collect data, analyze their results, and draw conclusions—in short, do independent inquiry? Yet asking for open-ended investigations is perilous in a real classroom: most students are, after all, novices, so it is easy for them to lose their sense of direction. Too often they flounder. Many students produce work that is disappointingly data-poor; or where the analysis is overly simplistic or just plain wrong; or where the conclusions are shockingly disconnected from anything they learned in class.

This is hardly surprising if students have been exposed only to laboratory activities from which most of the elements of independent inquiry are absent. Most traditional labs focus, intentionally, on experiencing phenomena, collecting data, and to an extent, on the analysis. After all, there isn’t time (many would reasonably argue) to have students design the experiments. As to coming up with their own hypotheses, we do have a curricular agenda, a path students need to follow if they are to take advantage of centuries of vicarious experience and thought.

So how do we prepare students for doing investigations, starting where they actually are? One way is to change how we begin a lab. Our goal is to give students important tools for independent inquiry, but within a structure that does not set the curriculum on its ear. The principles we describe here are evolving as part of an NSF-sponsored research-and-curriculum-development project intended to infuse more and better data analysis into the introductory physics classroom. We’ll describe three elements to our approach; they are more or less independent of one another. In fact, it may be a difficult—for the instructor or for the students—to introduce all of them at once, depending on the details of your situation.

The Defining Question and Its Answer: “It Depends”

One way to frame the beginning of any investigation is to ask a research question. But what is the right wording for the question? What should it encompass? We suggest making the question you pose one step more vague that you might expect. The litmus test is this: we want the natural answer to the question to be, “it depends.” Why? Because it motivates a natural rejoinder, “depends on what?”

An example: suppose we want students to time carts rolling down a ramp, and suppose our goal is that they learn about uniform acceleration. One obvious question is, “How does the time it takes the cart to go down the ramp depend on the starting position?” We suggest that a better start for the activity is to ask, “How long does it take a cart to roll down a ramp?”

This is more vague, so unanswerable as to be almost silly. Students answer, “it depends.”[1] We respond, “depends on what?” and now individuals, groups, or the whole class can brainstorm, briefly, what it might depend on. We encourage (and list) as many responses as possible. Very quickly, students suggest that the time depends on the angle of the ramp, the temperature, whether you push it, the weight of the cart, and so forth—and often omit the “obvious” salient variable, the starting position. If

---

[1] Of course, at first, real students just sit there. But with a little drawing out, they will soon be giving this answer in unison—even when you don’t expect it. This is a good thing.

they do omit it, we supply it when we have listed the others.

We point out that these “depends on” quantities are variables, and that the time (the dependent variable) depends on them.

Next, we ask informally which of these variables make the most difference with the setup we have, which are easiest to measure, and which are easiest to control. From that discussion, students decide (for example) that temperature is easy to measure, hard to control, but not very important; that pushing is important and hard to measure—but easy to control as long as you don’t push. Students may disagree about the importance of weight, but agree that distance and angle both make a big difference, are measurable, and easy to control.

At this point, if your goal—as we said—is simply to study uniform acceleration, you could explain to the students that while the other variables may have some effect, we are going to study the effect of distance. It will therefore be important to control the other variables as well as they can.

This discussion takes all of five or ten minutes, and can take place days before the actual lab activity. But even five minutes are important in a real classroom. Of what use is talking about what depends on what if you’re going to wind up taking the same measurements in the end?

First, it explicitly acknowledges other variables in the situation, and lets students think about them and what effect they might have. Acknowledging other variables makes the idea of controlling them more understandable. At first, control is informal speech (e.g., “we can’t control the temperature”), but the moment we choose to study one or two variables and control the rest, the word takes on special meaning. Since students have just been discussing the effects of the other variables; this is the perfect time for them to see that they have to hold them as constant as possible—especially those variables that will have the most influence on what we’re doing.

Finally, even though we teachers know ahead of time which variable we will study, asking about variables involves students in the process of identifying them and deciding what to measure. This is not just an illusion of free will; students can imagine what they would do in order to study some other variable (ramp angle, for example) and, eventually, do an investigation themselves.

The Power of Prediction

A second simple addition to the beginning of the lab—also good to do the day before—is to insist that students explicitly predict the results they will get. For physics situations like the cart and the ramp (and many others), this prediction can take the form of a sentence, a sketch of the graph of the relationship they think they will find, or a full-fledged, labeled and scaled graph.

What kind of prediction students can give depends on their experience, of course, but also on the role the lab plays in the unit in which it occurs.[2] It is pointless, for example, to have students predict when they have no reason to understand anything about the phenomenon; they need some background, either from common sense or from some in-class experience (e.g., watching the cart roll down the ramp without taking quantitative measurements[3]).

Of course, at the end of the lab—in the “conclusions” section—they will compare their result to their prediction.[4]

Again, this requires a few extra minutes. Of what use is it?

---

[2] In materials from the ISLE project (Etkina 2004), students perform or witness an “observational experiment” before they develop a prediction, and only then design a “testing experiment” to evaluate it.

[3] The Interactive Lecture Demonstration materials (Sokoloff and Thornton 2004) use this scheme to make prediction possible.

[4] We should note here that for students, making predictions and being willing to compare them to reality means taking risks. We all resist being explicit about our predictions and judging them; we need to create a class culture in which students are willing to be wrong. Part of creating that culture is to be sure to point out the inevitable aspects of students’ predictions that are right.

First, making an explicit prediction (and here we mean, actually writing one down) forces students to think in advance about the phenomenon they will study. In making a prediction, they cannot simply follow the recipe in the lab manual. And then, when they are actually doing the lab, students have a better way of telling when things go wrong—or take an unexpected turn.

Second, these predictions give us teachers interesting material for assessment, especially formative assessment, the kind that helps us learn what our students are thinking. To see what we mean, let's consider the types of predictions we are likely to get.

Overall direction. Using the carts example, a good prediction would be the phrase, "the farther the cart goes, the more time it will take." While this is at a basic level, it is a perfectly good prediction. And it's important to acknowledge it, especially since "The farther it goes the less time it will take" is not uncommon.[5] This kind of confusion can undermine a student's whole understanding of mechanics, but it is easy to clear up if we detect it. (How to clear it up? One good way is to insist, in the conclusions, on a clear explanation of why the prediction did not match the data.)

Qualitative graph. A quick sketch of a graph is a more sophisticated response. Often, the graphs students produce will be more-or-less linear, mirroring the "overall direction" prediction above. But we can gradually get more students to commit to a curvature in their predictions (See Figure 1). Explaining the curvature can be a valuable challenge to students, forcing them to think clearly about rates—or at least to reveal their current thinking to us so that we can see what students understand.

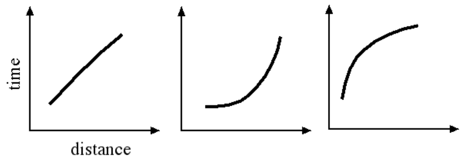

Figure 1: Predictions might be more or less linear, or students may predict that the graph of a phenomenon curves one way or another.

Quantitative Graph. An even more sophisticated, specific, and risky response attaches numbers to the graph axes. With such a prediction, a student gives us all of the information from the other two types of predictions, but also shows us his or her sense of quantity. How long will it take the cart to roll down the track? Some students—at least on their first such attempt—can easily miss by factors of 10 or more. They may have little sense of how many seconds a fairly brief event takes.

This should not alarm us; we don't often practice estimating what we are about to measure. In a recent workshop, we asked high-school teachers to predict, before an activity, how the mass of a handful of Hershey's Kisses would depend on the number in the handful. In their predictions (as in the activity that followed) the slope of that linear relationship is the weight of one kiss. Their estimates ranged from about 1 gram to about 50 grams per kiss. Afterwards, one teacher confessed, "I should have known that 50 grams was too much—that would make ten kisses be more than a pound!"

If we frequently ask for these predictions before lab activities, we can urge students to become more adventurous—and more quantitative.

Thinking about Measurement in Advance

When we made the opening question more vague ("How long does it take a cart to roll down the track?" Instead of "How does the time it takes a car to roll down the track depend on the distance it rolls?") we could have gone in the opposite direction, and made the question more specific: How long will it take this cart to roll down this track from here?

This question is also a little silly in a physics class. Here the answer is not "it depends," but rather "I

---

[5] What can that student be thinking? If we have the prediction in writing, we can ask and find out. On one occasion, a student correctly reasoned that the cart would go faster, but then deduced (perhaps misusing *distance = rate * time*) that the time would therefore be less.

don't know, just try it and see." Exactly. This gives us a chance, just before doing the actual activity, to decide exactly how to take the measurements we need. The traditional lab prescribes this ("Measure the distance from the front of the cart to the bottom of the ramp," etc.). Alas, this gives students no chance to grapple with how to measure well—that is, to get measurements consistent with the conceptual point we're pushing in this lab (under uniform acceleration, the rolling time goes as the square root of the distance).

We don't have the time for students to design every lab, but we can take a few minutes to let them think about the measurement process, to practice measuring, and to see the consequences of poor measurement technique. We recommend having the class take a few measurements of the same equipment, and then compare results and comment on repeatability. For example, have a few class members—perhaps one from each group—use stopwatches to time a cart rolling 150 cm down a ramp at the front of the class. The whole class can offer suggestions as to the best way to time the cart, exactly where to put it, and how to release it to minimize the "push factor." The instructor elicits and records the measurements on the board. The class discusses the spread: is it reasonable? Should we change anything? Then we repeat the measurements. Are the numbers consistent with the first batch? How is the spread? This analysis should be very informal—no need to calculate standard deviations!—but will result in a class awareness that there are better and worse ways to take measurements, and that being careful pays off.

Conclusion

We believe that these three ideas for beginning a lab—whether used together or separately—will help us give students more insight into any lab, and more understanding about what it means to do inquiry, without derailing the lab's purpose or a class's syllabus.

While the example here—the cart—has been from a quantitative physics context, you can apply this advice to any introductory lab. Where in this box will the pill bugs (sorry—*isopods*) congregate? (It depends—is part of the box dark? Are there any leaves? Is the box level?) Identifying variables, predicting, and measuring—in this case, counting—are always vital elements of inquiry.

And why should we care? To be sure, these experiences may make for better end-of-term projects, but the real benefits are deeper. In contrast to most schoolwork (and most tests) real-world questions are not well-formed.[6] We need citizens who recognize that vagueness and can give it some definition, who can risk predicting, and who appreciate how hard it is to come up with a definitive result.

References

Etkina, E. 2004. *Investigative Science Learning Environment* (ISLE) Program. Description at http://paer.rutgers.edu/PT3/introlong.html.

Posner, Dave. "What's Wrong with Teaching to the Test?" *Phi Delta Kappan*, June, 2004, Volume 85, Number 10. Online at http://www.pdkintl.org/kappan/k0406pos.htm

Sokoloff, D. R. and Thornton, R. K. 2004. Interactive Lecture Demonstrations: Active Learning in Introductory Physics. Wiley.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Award Number DMI-0216656. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the National Science Foundation.

The author is also grateful for support and comments from practicing teachers, especially Bryan Cooley and Richard White.

---

[6] Dave Posner (2004) writes, "Reducing…more or less vague problems to more concrete questions is a major part of the problem-solving process in the real world."