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Fake papers as investigation prompts

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Abstract

We describe an intriguing genre of assignment in which students respond to a fake scientific paper by designing an experiment to test its claims. Put another way, we ask students to be experimentalists, albeit in an artificially controlled and prescribed domain; we hope that through this, students get a better picture of what science is about and why we are asking them to learn the material.

As one might predict, many students are perplexed by this assignment, and many responses are weak. Nevertheless, their performance illuminates aspects of student (mis)understanding, and suggests directions for curriculum and assessment.

Background

For many years, progressive physics educators have despaired over what they see as shallow understanding of important principles even by apparently successful students. In response, they have de-emphasized lecture as the primary instructional mode, reasoning that more active learning might be more successful. Some have tried to give students more control over laboratory exercises, in particular to make labs less ‘cookbook’, so that students make more decisions about procedures and equipment. A number of researchers, developers and projects have produced physics education materials aligned with these goals, including *Physics by Inquiry* (McDermott *et al* 1996) and the *Workshop Physics* and *RealTime Physics* materials (Laws 2004, Sokoloff *et al* 2004). Others have developed improved, more ‘minds-on’ instructional practices such as Modeling Instruction (Wells *et al* 1995) and Interactive Lecture Demonstrations (Sokoloff and Thornton 2004).

Another way to frame this progressive, active approach to learning physics is to say that we would like the students to act as scientists. If we let students do this *completely* on their own, however, the process could take thousands of years. As teachers, we have a responsibility to direct the class somehow, to point out the giants onto whose shoulders students should clamber. Thus we perform a balancing act: we give students rich environments and enough freedom that they can make physics their own, yet direct them to find essential paths and to learn essential skills and concepts. How can we make assignments that fit with our philosophy?

Before we discuss one answer to that question, let’s ask why we’re teaching physics at all. Most citizens do not need to know about the Mössbauer effect, the thin lens formula or even how to draw a free-body diagram. But they do need to evaluate scientific claims intelligently, and it would help them to be able to use and recognize scientific, evidence-based reasoning, and be able to distinguish a scientific claim from some other

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type. Thus the point of the course is not only to learn physics, but also to experience science, of which physics is a particular (and particularly interesting) example.

Various Standards documents recognize this: *Benchmarks for Science Literacy* (Project 2061, 1993) and its cousins have 'The Nature of Science' as their first benchmark. The National Science Education Standards (National Research Council 1996) have a 'Science as Inquiry' standard that explicitly includes epistemological issues—how we know what we know—and the nature of science. Yet a typical curriculum does not give the nature of science much play. This is understandable: there is a lot of content to cover, so it is hard to spend time on what some see as a philosophical digression. Textbooks occasionally and briefly address the nature of science, or embed some related material in boxes containing mini-biographies of famous scientists. This is good, but (as we shall see) does not teach students, for example, what is required in order to test a hypothesis, or what happens when the hypothesis fails the test.

And it certainly doesn't give students an experience of their own that they can use to understand how science works.

Etkina and her colleagues (see, e.g., Etkina *et al* 2002) describe, as part of their *ISLE* project, an enticing way to think about experiments in real science and in the lab. They classify experiments as *observational*, *testing* or *application*. In the ISLE system, students use observational experiments to find a model, pattern or explanation for a phenomenon. Then, in a testing experiment, they test a specific prediction that arises from that model. In application experiments, students use their understanding of the phenomenon and its model in new ways.

The guts of the epistemology is in the testing experiment. Here is where a hypothesis can get shot down, where falsification happens. This is the step that distinguishes science from other endeavours.

We find this aspect of physics education particularly interesting. Can we adapt contemporary, constructivist, progressive principles of curriculum design to help students understand this central epistemological pillar of empirical science? And in doing so, how do we direct the students to address hypothesis testing while advancing the curriculum content and, at the same time, giving students as much freedom as possible?

What we did

Our idea was to create an open-ended assignment that had a number of properties:

- It gave students freedom to design an experiment.
- It focused on particular content.
- It required a specific form of response.
- It gave students a first-hand experience of dealing with hypothesis testing.
- The prompt was demonstrably incorrect. More about this shortly.

As a prompt for our assignment, we created a page written and formatted in the style of a short scientific paper. The paper made a specific claim; students were to design and perform an experiment to test the claim, and report on their findings.

To show more clearly what we're talking about, we present an example in the Box. (You can find more of these at www.eeps.com/resources/. Look for the *Annals of Plausibility*.)

All the papers in our set of prompts are *wrong*. Even though each one makes a plausible scientific claim, proposing a model or relationship that seems reasonable on the surface, it will not hold up to experimental testing.

In the case of Finkelbottom and Priest, it is true that rocks fall more quickly than cotton balls. And the functional model produces results that fit with the common-sense observation. But the model in equation (2) makes specific quantitative predictions that will not pan out. Air resistance does not simply reduce the acceleration as the authors claim. If the students do their jobs well, they will discover this, and they will be able to present data to refute the claim in the paper. They need only a measuring tape, a stopwatch and a cotton ball.

Conceptually, this resembles an ISLE 'testing experiment' in that students are to make specific predictions based on a model and then design an experiment to test them. In contrast to ISLE, however, we have constructed the prompt for the students instead of letting it arise organically from the students' work. While the ISLE technique is philosophically very attractive, our prompts may fulfil several related purposes not inherent in an ISLE activity:

On the descent of cotton balls: a theoretical perspective

J K Finkelbottom and P R Priest

Abstract. Cotton balls fall more slowly than rocks in most situations. We present an extension to the traditional Newtonian view of objects to include free-falling cotton balls.

Cotton balls (which are sometimes made of Rayon) are puffs of fluff, roughly spherical, with a diameter of about 3 cm and a mass between 0.5 g and 1.0 g. If you drop them, they fall.

It has been observed, however (Galileo and Snerd 1998), that if you drop a rock and a cotton ball simultaneously from the top of a tower, the rock lands first.

Evidently air resistance slows the cotton ball more than the rock. We suggest that its effect is greater because the cotton ball is lighter.

Our reasoning is this: Each air molecule, on impact, imparts a small force to a falling object. Using the traditional force formula $F = ma$ (Newton 1687), we see that each collision effectively reduces the gravitational acceleration of any object falling through air by an amount that is inversely proportional to that object's mass (i.e. $a = F/m$). Thus the light cotton ball is slowed more than a comparably sized (and heavier) rock.

Therefore we should modify the formula for the distance s fallen in time t. Instead of the traditional

$$s = \tfrac{1}{2}gt^2 \tag{1}$$

where g is the acceleration of gravity, we suggest that the correct model for falling cotton balls is

$$s = \tfrac{1}{2}kt^2 \tag{2}$$

where k is an acceleration smaller than g. Though the truth of our theory seems self-evident, we await confirmation from experiment.

- Pre-built prompts may serve as easy entry points for instructors who are not yet ready to adopt a program such as ISLE in its entirety.
- Prompts like these might make excellent uniform assessment tasks.
- That the prompts are all wrong gives students experience with falsification; they learn what happens to hypotheses that do not get confirmed.
- The format and style of the prompt give students practice in decoding science prose; furthermore, the activity demystifies the style: even though it sounds high-falutin', and has good-looking equations, it's still wrong.

Results

Responding to a task like this turns out to be very difficult for students. We presented this task to approximately 80 students, mostly sophomores and juniors in the introductory physics sequence for majors at a large state university. The course had a traditional format of three lectures per week, with a three-hour lab once a week. This was given at the end of the first semester, after the students had presumably mastered basic mechanics.

We expected students to have trouble, but not as much as they had: A large majority of students—up to 80% in some lab sections—who tested the 'Finkelbottom hypothesis' concluded that the hypothesis was correct.

Instead of testing the applicability of the model (equation (2)) to a wide range of experimental conditions, many students tested how that equation 'worked' for one specific case. For example, they might carefully measure the average time t it took the cotton ball to fall $s = 2.0$ m as 0.75 s, apply this time and distance to equation (2), determine the value of k to be 7.1, and happily report that the hypothesis was correct since k was less than g. The better students in this group would measure the time for that one height repeatedly, and use the variation in their measurements to estimate the uncertainty in k also.

There is an interesting subset of students within the 'wrong answer' group: these students measured the time for the cotton ball to fall different heights. They then calculated the value of k as shown above, and noticed that it changed with initial height. For short drops, they found that k was approximately equal to g, and that it decreased with increasing fall distance. These students then declared the theory to be true, with the caveat that the 'constant' k was dependent on initial height.

Of the small percentage of lab groups who correctly showed the theory to be incorrect, about half did so by measuring k for different heights (as described above) and showing that k was not a constant within the bounds of their experimental error. The other half plotted distance versus time and showed that although the curve was approximately quadratic for small t, it quickly became linear in disagreement with the model.

What do real cotton-ball data look like? Figure 1 shows three graphs of the same data, presented in different ways. Note how the data are inconsistent with uniform acceleration.

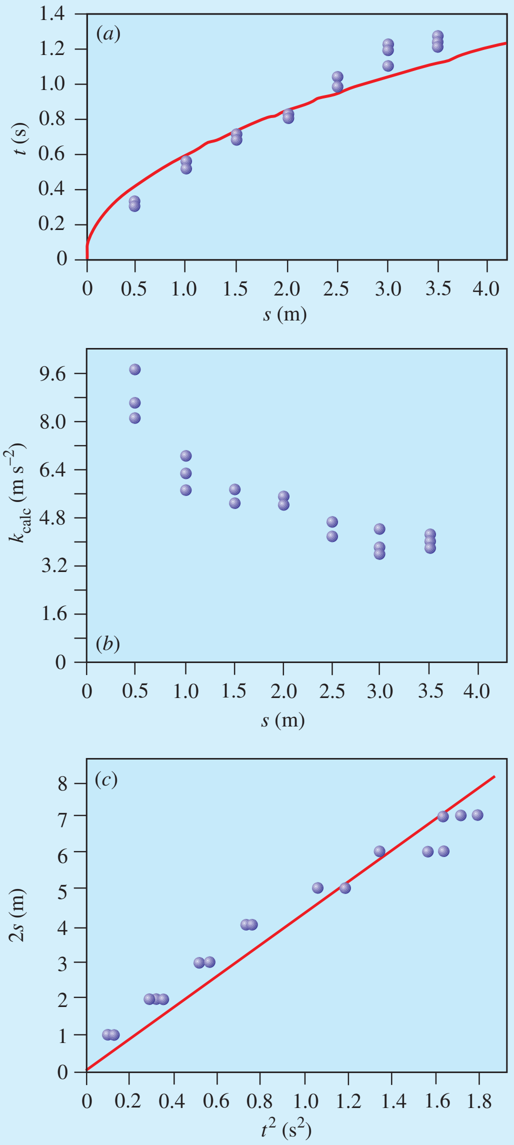

Figure 1. Three cotton-ball graphs that could disprove the Finkelbottom hypothesis. (*a*) The square-root model $t = \sqrt{2s/k}$; (*b*) how a calculated k varies with height; (*c*) a 'linearized' approach–a plot of $2s$ against t^2.

Discussion

We are tempted to dismiss the first group—the ones who just found k and stopped—as trying simply to finish the assignment in the way they know best: find an equation, solve for the unknown, identify and measure measurable quantities and make the relevant calculations.

But the second group of students who showed that the 'Finkelbottom hypothesis' was correct offers us an important insight into what may be going on. After all, they took the measurements from different heights and made the relevant calculations. They found that the constant wasn't constant. They had all they needed to show that Finkelbottom was wrong. Why didn't they?

We have two main conjectures. First, they did not really see what the model was, and therefore did not know how to test it. In particular, they didn't see that the model described a *relationship* between time and distance, a specific prediction about the functional form of the motion of the cotton ball. Their measurements—times from different heights—gave them good empirical data about that relationship. But instead of comparing the data to the function, for example by trying different values of the parameter k, they calculated k separately for each observation.

In retrospect, this is not surprising. When students do calculations with actual data, usually as part of a lab, we typically ask them to come up with a single numerical answer: the acceleration of gravity, the coefficient of friction, the resistance of some component, the index of refraction. In terms of the model, however—the formula in the Box—this number is only a parameter. It doesn't determine the functional form of the relationship; it is simply the 'letter that's left over' when you plug in the values for the things you can measure. The students never face a situation in which there is any question about the functional form of a relationship; they have never seen a 'constant' that might not be constant—nor what that inconstancy implies.

That is, many experiments we use to *verify* some principle are really *application* experiments in the ISLE taxonomy, ones that assume that the model—the functional relationship—is correct.

The second conjecture is that students are therefore lulled into believing that the equation must be correct, because it always has been. Consider: these students, prior to this laboratory exercise, had 'verified' in some sense:

1. Newton's second law, $F = ma$
2. Kinematics equation, $y = y_0 + v_{0y}t + \frac{1}{2}at^2$
3. Centripetal force, $F_c = mv^2/r$
4. Coulomb's law of friction, $F_f = \mu F_N$
5. Work–energy theorem, $W = \int F\,dx = \Delta K$
6. Impulse–momentum theorem, $J = \int F\,dt = \Delta p$
7. Conservation of energy, $E_i = E_f$
8. Conservation of momentum, $\boldsymbol{p}_i = \boldsymbol{p}_f$
9. Rotational inertia of point masses, $I = mR^2$
10. Simple pendulum, $T = 2\pi\sqrt{L/g}$
11. Hooke's law, $F = -kx$.

Is it any surprise, given that in each of these experiments they were expected to 'prove the theory right', that the students would go through considerable mental gymnastics to prove the 'Finkelbottom hypothesis' correct also?

In other words, we have not been training our students to think, explore and discover new truths for themselves, but rather providing them with the tools to 'prove' whatever is expected.

Suggestions and future plans

Given that there are more wrong ideas than right ones, shouldn't we be better equipping students to deal with the more prevalent case? These students were successful science majors by most conventional measures, yet they could not disprove a bogus hypothesis when all it took was a few simple measurements and basic kinematics. Do we have to revamp everything?

Probably not. It may just be a case of needing to bring it to students' attention. We think students would be well served by any or all of the following:

- Having more than one lab experience like this, so that students can get feedback on their first attempt and simply pay more attention the next time.
- Having more out-of-lab assignments that involve realistic data. In almost all textbook problems, the data fit the proffered model exactly. Data-rich problems might be good contexts in which to talk about parameters and variables, and how they can change roles depending on the situation.
- Showing data that do not completely fit the model, for example where the model has a limited range of applicability. The current–voltage relationship for a light bulb comes to mind.

We hope these lab prompts get tested in less traditional formats, for example classes that use *Workshop Physics* or the *ISLE* materials, and classes with more interactive pedagogical strategies such as modelling and interactive lecture demonstrations. We imagine that tasks like these would be useful supplements to any of the more innovative classes and that, furthermore, students who have experienced a richer culture of inquiry would naturally do better in showing just where Finkelbottom and Priest went wrong.

While the truth of this assertion seems self-evident, we await confirmation...

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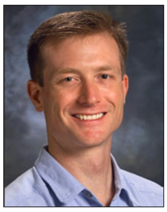

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