The Physics Education Research Column

Nature: Judge, Jury and …

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Who's the Boss? Nature.

I humbly propose a new model for education. We are all very familiar with the now somewhat unfashionable, yet prevalent, teacher-centred learning model: "All eyes to the front! Tim, pay attention - what I'm covering is important!" Here, the final word is always the teacher's. Next is the more au courant student-centred model, where the final word is often the students'. That's a big step in the right direction – getting those teachers to pipe down for a bit. But what we really need in science education is a nature-centred model, where the final word goes to Mother Nature. What better authority for knowledge and insight do we have?

Our Better, Nature

If there is one critical lesson about science for our students, it is our slavish devotion to nature's every word. Like doting suitors we ask her questions and take great pains to listen to her nuanced and subtle answers. Our quaint notions and fanciful ideas (like those involving me and Scarlett Johansson … sigh) only last so long before they are dispelled through empiricism and logic. What lesson could be of greater use? Are you listening, politicians? As educators, we need to transition away from being the figure of authority. Physics Education Research (PER) has shown that students learn best when they are talking about and explaining physics to one another. They have to wrestle with core concepts of physics themselves in order to build genuine understanding. Researchers have studied (empirically) the evolution of students' opinions about physics and about science in general as they progressed through reformed, student-centred, educational programs. Sure enough, the researchers' quaint notions concerning the goings-on of the student mind were dispelled.

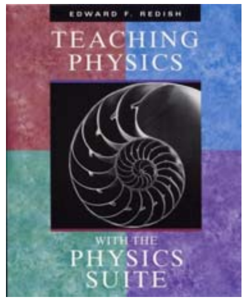
Is Physics Real?

Who in their right mind would ask a question like that (aside from climate change deniers, creationists and Italian judges)? Pesky physics education researchers would. It has been hoped that the shift to student-centred learning would help students develop more expert thoughts and opinions about the operation and applicability of physics. To measure this great shift in thinking a few different surveys have been developed, the most recent being CLASS (Colorado Learning Attitudes About Science Survey). Rather than ask students outright and get the answer we want, the researchers were a little coyer. In the CLASS survey a number of innocuous statements are presented for students' consideration, such as:

28. Learning physics changes my ideas about how the world works.
30. Reasoning skills used to understand physics can be helpful to me in my everyday life.
35. The subject of physics has little relation to what I experience in the real world.
37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.

In almost all cases, the proportion of students who agree with expert responses to these questions *dropped* after a semester of instruction, regardless of the format – traditional lecture or active engagement. Typical results are a drop from 72% ±1% to 65% ± 2%. Even for courses with high levels of group work and hands-on experimentation, the results are mixed at best. It seems that even with our best efforts, our teaching leads to fewer students believing in the reality of physics. What would Mother Nature say?

The psychology behind this disconcerting phenomenon is explored in Edward Redish's excellent book *Teaching with the Physics Suite*. Redish notes that "students can attach new knowledge to their existing knowledge structures as something separate and only relevant for the context of solving problems in a physics class." (See Dr. Spence? Citing can be easy!) As teachers we have all witnessed students' remarkable ability to compartmentalize knowledge. We've all watched them stitch unnatural ideas together into their misbegotten Franken-solutions. Redish proposes a few goals for our teaching to encourage a rapprochement between students and physical reality:

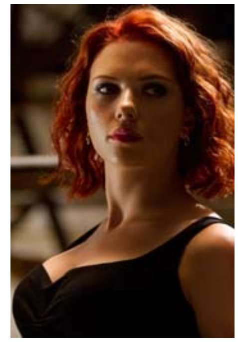


- Our students need to understand how the physics they are learning is firmly rooted in the physical world.
- Our students need to learn both *how* to use the physics they are learning and *when* to use it.
- Our students need to connect the physics they are learning with their own experiences.

It is important that we upgrade our traditional problems and classroom examples to involve "real-world" situations. But that will not correct this problem. Students will always appeal to the teacher or the textbook for verification and validation of their results. The connection with nature is not secured. Cooperative group work allows students to work together to explore physical phenomena, find patterns and solve problems. This is another big step forward, but this may only be Aristotelian physics: while their ideas may be self-generated and even internally consistent, they have not been tested against nature. And to paraphrase the Tick, Mother Nature is a harsh mistress (just ask Bohr and Einstein).

A Modest Proposal

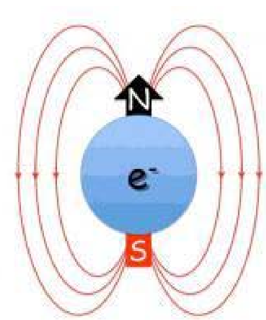
What should we do about this? I have a few suggestions, but first, full disclosure. I am accepting kickbacks from Mother Nature in the form of air, water and general foodstuffs, and I have not actually run the CLASS survey with my own students, so I have no empirical results. Nevertheless, my anecdotal results leave me hopeful (unlike with Scarlett Johansson – did you see her in *The Avengers*?). Here are my suggestions:



(1) Agree on "Close Enough"

Long before I changed my teaching practice my students had been "testing" predictions in "experiments". But what they were doing was bogus, in part because they did not understand how to decide whether a measurement agrees with a prediction. What process, after all, is more critical and unique to science than this? If my students happened to measure the exact same value as their prediction they would contentedly move on. If they didn't, they would show it to me and I (the voice of authority!) would say, "close enough," and the veil was again draped over Mother Nature. Looking back on it I think I could actually see the cloudiness forming in their eyes.

To peel back those veils students need a basic understanding of errors. We do a single lesson on measurement and error, but we do not do error propagation. My goal is to help them have a sense for errors arising from measurement tools and to help them crudely estimate errors in calculations. This can be as simple as "the calculation gave a result of 1.2 m which I wrote with two significant figures. So the result is reliable to within ± 0.1 m". I make it clear that this is only a very rough approximation of what they will later learn, but it sets the right conceptual framework. Once armed with errors for their predictions, it now makes sense to discuss what "close enough" means. "I measured a result of 1.1 m ± 0.1 m. They



are within the error range of each other, so the result agrees with my prediction." Don't forget, physics is all about being close enough - we never actually get it "right". Great excitement comes from getting closer, getting that next digit for the electron magnetic moment, but we will never get them all.

(2) Test the Obvious.

Make regular tests of seemingly simple results. Here is an example: when my grade 12s learn how to analyze forces on an incline, we predict the size of the force required to hold a cart at rest and then test that prediction. A test such as this could easily be dismissed as trivial, obvious, or a waste of time – after all, it involves such simple math ($mg\sin\theta$). Try this with your students and watch what happens. It's really quite fascinating. I predict you will see surprise, amazement, excitement, a bit of relief, and it is true, some indifference (you can't win'em all). I observed largely the same results doing this with OISE teacher candidates as well. Something important happens when making this test. What exactly it is, I'm not sure, but I have a hunch that for most students, once you start doing math - any math - things become very unreal. Examples like this are quick, simple, and important - and occur throughout my gr. 11 and 12 courses.

(3) Talk About Your Feelings

The human body is an amazing apparatus complete with a wide array of sensory instrumentation. Students need to learn how to interpret their physical sensations in light of their emerging physics understanding. This is real kinesthetic learning. When their physical feelings remain at odds with the "rigorous" physical theories they learn, we leave them facing a choice – which is actually correct? Should we be surprised when they regularly choose in favour of their own physical intuition?

What does it feel like when you accelerate? As long as we're not talking about gravity, we feel a "push" in the direction opposite to our acceleration. Passenger vehicle examples like turning a corner or hitting the brakes are "real world" situations we routinely use with our students. They invoke their intuitions and describe mysterious forces away from the centre or throwing them forwards. Their sensations are not wrong, but we need to help them reason through what is happening and reinterpret what they feel.

Do we feel weight? Really? Place a heavy book on your hand. You are not feeling the book's weight, our unfortunate synonym for the force of gravity. The weight of the book does not act on your hand. The gravitational interaction between you and the book is outrageously small. You are experiencing another interaction involving the normal force (electromagnetism). Proof: have someone lift the book off your hand. Gravity doesn't just turn off like that. We, for the most part, "feel" normal forces, like the side door of the car pushing inwards against us as we turn the corner.

(4) If You're Right, Nature Nods

What about all those stock problems students "need" to practice their physics skills? They don't need nearly as many as we might think. I do on average two in-class problems with my grade 12s for each major unit. The students know these as the "physics challenges". They consist of a thought-provoking problem requiring about 70 minutes to solve. The crucial final step in each challenge is the testing of their solution. Put an object on a digital balance on an incline – predict the reading. Release a mass attached to a spring – predict how far down it will fall (video 1, video 2). Fire an electron beam through an electric field - predict where it will deflect to. They know their work is correct not because the teacher says so, but because it works. My students get really pumped up about these tests – watching the physics actually happen just as they have predicted is a great reinforcement of so many things. In other lessons we appeal to simulations, which may not be quite as good as the real thing, but it still helps to short-circuit the teacher/textbook authority loop.

(5) Bring Out the Toys

Technology may be the direct route into our students' lizard brains. They eat, sleep and breathe their gadgets and gizmos. They also get a real kick out of discovering that the physics principles they are learning in class, apply directly to their toys. To make this clear, and not just a teacher's promise, a test is required. My students place a piece of tinfoil between a charged ebonite rod and an electroscope and watch the leaves fall. Then they wrap the foil around their phone and watch the bars disappear. That's when a connection is made. They experiment with polarizing filters and happen to notice the filters turn off a laptop screen "accidentally" left open during class. Then the phones come out, soon followed by the excitement.

[When You're Good to Mama](#) …

So it's time we give Mother Nature her due, her starring role in our physics production. I have found these suggestions to have made a substantial impact on my students, helping them to better understand that physics is real and not simply a torturous game invented by teachers. The side benefit of this approach, I believe, is that the work students do each day in class feels much more real to them. Engagement and motivation of my students are high, course attrition is low. According to a student who failed the first half of grade 12:

> "My passion for physics sparked, and I realized it could actually be enjoyable! I like the fact that I can explain to people how the stuff in our daily life works (from storms, to magnetism, to putting coffee on a table)."
>
> - *Grade 12 student from York Mills C. I.*

So I predict when you're good to Mama, Mama's good to you … and your students. Test my predictions.