The argument for change

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Editor's note:
This is the fourth in a series of articles by Chris Meyer describing his experiences implementing a reformed physics program. Please e-mail him directly if you have any questions or feedback

Through this series of articles I have been sharing my experiences with experiments in reformed physics teaching. I taught physics in a traditional, lecture-based manner for ten years, all the while dabbling with new strategies. I tried some cooperative group problem solving, experimented with a few guided-inquiry activities, and made a general effort to boost the hands-on components of my course. I really liked the direction of the new techniques, but my students weren't getting the enhanced learning that was my goal. They had difficulty understanding my changing expectations and didn't have time to adjust to the new strategies before we were back to the old routine of lecture-and-practice. After some deep reflection, I decided that it was time to 'jump in the deep end': to make a fundamental and dramatic change to my classroom pedagogy.

Visit my classroom today and you will not see me behind the teacher's lab bench talking at the students. Instead you will see students working in cooperative groups, tackling guided-inquiry activities and problem solving challenges. They have become the main actors in my class and I am now part writer/director and part curious audience. They do the vast majority of the demonstrating, writing and explaining; I listen and ask probing questions. It's no longer the 'Mr. Meyer physics show'; instead, it's a hive of student activity with the understanding of physics as the queen bee.

The ideas underpinning my new physics course come from Physics Education Research (PER). Over the past thirty years physicists have been engaged in the study and reformulation of their own educational practices. An important discovery[1] from their research is that students learn most effectively through social interactions. That discovery, combined with conceptually oriented constructivist activities, has led to a group-oriented model of physics teaching. The finest example of this is *Workshop Physics*[2], which serves as the primary model for my course. Data comparing student performance on standardized tests under the old and new teaching formats are very impressive and difficult to ignore (Figure 1)[3]. The spike at the right of the graph represents the results of the implementation of *Workshop Physics* by its founders at Dickinson College in Carlisle, Pennsylvania.

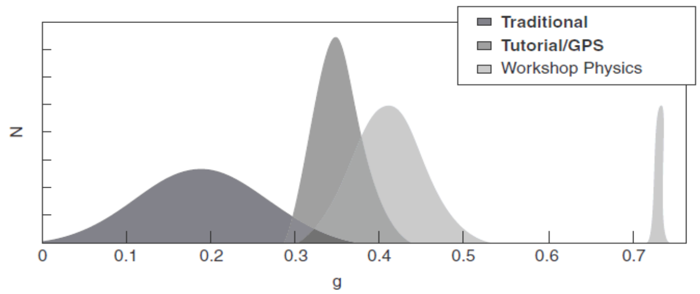

Figure 1: The proportion of students verses fractional gain, g (a measure of improvement), on the Force Concept Inventory for three instructional formats.

The evidence clearly demonstrates that lecturing is an inferior method of teaching. In the past, I sometimes rationalized the lacklustre achievement of my students by musing: "Well, physics isn't for everybody, especially those who are weak at math. Besides, I do have a handful of students who really get it, and that makes it worthwhile. But I am glad the others are in the course. I'm sure they will benefit from their experiences in the class."[4] With such thoughts I largely neglected my responsibility to frankly determine the needs of all my students and to teach in a way suited to their learning styles rather than in a way that was familiar or comfortable for me.

It is important to look at the big picture and decide why we teach physics. Both students and society have changed greatly over the last thirty years. Students enter our courses with a very unclear notion of what physics is or why it may have value aside from being a required course for post-secondary programs. They leave our schools and find themselves in a working world of great technical demand. Society as a whole depends keenly on the future success of science and requires a citizenry capable of informed decision-making. Physics has an important role to play as the 'liberal arts' of the sciences, with its strong focus on problem solving, mathematical analysis, logic, and experimentation. The fundamental science, physics offers the skills that are key to so many fields of science and technology. If, despite the growing need across society for these skills, student enrolment in physics is declining, we have an even greater obligation to rethink what we as teachers offer our students.

The need for better physics education may actually be most keenly felt in the field of biology. Biology is in the midst of a period of revolutionary change, as the disciplines of the physical sciences, mathematics and engineering are more and more closely incorporated into it. In 2009 the National Research Council in the Unites States issued a roadmap for a "new biology"[5], outlining the pressing need for an emphasis in biological instruction on problem solving, quantitative reasoning and fundamental physical understanding[6,7]. Without these skills, students are much less able to participate in the blossoming of biology's cutting-edge, and often physics-related, disciplines[8]. These necessary changes are beginning to take place. The University of Toronto has recently reformed its physics course for life sciences students by replacing its tutorials and labs with "practicals": group activities similar in style to *Workshop Physics*.

With my own reformed course, I have observed very positive changes in my students' learning skills and attitudes. The level of commitment they demonstrate through their daily work is much higher than before. I teach about eighty grade 12 physics students a day and it is rare that I have to remind them to stay on task. Their diligence is remarked upon by supply teachers. This means that each day they have a good 65 minute physics 'workout'. The activities are designed to encourage students to talk and write about physics in their own words. Through their discussions, I hear evidence of them grappling with the key challenges and conundrums of physics that are often casually explained away or glossed over in a lecture. The hands-on activities allow for a regular back-and-forth between observations, principles and calculations such that students frequently experience the vital connection between theory and physical reality. The hands-on aspect also assists students in building a stronger concrete and intuitive foundation for the new ideas they are learning. Mathematics is still the backbone of physics in this course, but it takes a conscientious backseat to concepts and ideas. This allows many more students access to physics insight and it provides greater motivation for the supporting math when it is developed.

Bringing about change presents many challenges and requires the teacher to develop new skills. I needed to learn how to assist students with their interpersonal relationships and collaborative skills since I am now a leader of many small teams rather than one large class. I have had to become a guidance counsellor to help students adjust from a largely self-centred philosophy of learning to one where they begin to care about the understanding and involvement of their fellow group members.

It can be quite a challenge to write or assemble all the materials for a complete and coherent reformed course. I have drawn upon the best models from a variety of sources and adapted them to the needs of the students at my school. I hope to save others the need for this labour: all my resources are freely available online.

Veteran teachers will surely be familiar with the periodic educational fads that waft in from the faculties of education. Many of us have developed a healthy scepticism towards ideas that seem jury-rigged for the high school and physics environments. Physics Education Research is substantively different from anything I have seen in the past. It is a genuine science of teaching where physicists are tackling the problem of education using their most powerful tools: modelling, designing, testing and analyzing. All of this is done with the goal of improving student understanding, and results are tested as rigorously as is possible for the highly varying, non-linear system of adolescent humans.

If I have managed to pique your curiosity or to tempt you a little, and you would like to investigate a different way to teach, consider starting with the resources I have made available on my website: http://www.meyercreations.com/physics. There you will find all my digital materials including the grade 12 course activity book, PowerPoint lessons, pedagogical presentations and articles. I will be presenting two workshops at the OAPT Conference, May 12-14 at McMaster University where I can answer your questions in person. However, there is no substitute for seeing change in action. I encourage anyone interested in making a trek to my school to contact me and arrange for a visit. Make your own observations and draw your own conclusions. I wish you the best of luck with your own experiments in reformed physics teaching.

[1] Which was not really a discovery to anyone except physicists.

[2] The Workshop Physics homepage: http://physics.dickinson.edu/~wp_web/wp_homepage.html

[3] Redish, E. *Teaching Physics with the Physics Suite*. John Wiley. http://www2.physics.umd.edu/~redish/Book/09.pdf

[4] It is interesting to note that is his introductory lectures in physics, Richard Feynmann noticed the same thing and makes a similar self-justification. Feynmann, R. *The Feynmann Lectures in Physics.* Addison-Wesley (pg. 5)

[5] *A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution*, Washington, DC: National Academies Press. www.nap.edu/catalog.php?record_id_12764

[6] *Integrated Biology and Undergraduate Science Education: A New Biology Education for the Twenty-First Century?* CBE Life Sci Educ 9(1): 10-16 2010. http://www.lifescied.org/cgi/content/full/9/1/10

[7] Dr. Monika Havelka at the University of Toronto, Mississauga has presented a report which shows the strongest predictor, by a substantial margin, of student success in first-year biology is their grade 12 physics mark.

[8] For example: http://www.healthzone.ca/health/newsfeatures/article/866651--toronto-scientist-shaking-up-field-of-infectious-disease

Science Student TALK Science

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Uxbridge Secondary School is located northeast of Toronto in the Durham District School board. I have been teaching physics and science at Uxbridge Secondary School since September 2000 and am proud to say that science is truly alive at USS through the dedicated science teachers on staff and the enthusiasm for science that our students demonstrate throughout the school year.

On February 10, 2011, I had the pleasure of watching some of Uxbridge Secondary School's senior science students conduct presentations on Nanotechnology and Rocket Propulsion. The Uxbridge Secondary School Science Department organized its first ever USS Science TALKS event in the hopes of spreading the love of science to students and community members. Jeffrey Highet, Spencer Richards and Elena Routledge conducted themselves in a very mature and professional manner as they faced a large room of 150 people including students, staff, parents and community members. As I sat in the crowd, I realized that what we do as science teachers truly do have profound effects on our youth. Who would have ever thought that some of our students would be provided an opportunity to share their passion for science with an audience of that size! The event was not complete without a guest speaker. Richard Epp from the Outreach Team at The Perimeter Institute for Theoretical Physics was truly a highlight of the event. Students were fascinated as Richard walked the audience through the very nature of science – to question our reality. As the wonders of "Alice and Bob in Wonderland" launched the discussions, students and parents continued to question Richard about our Universe. The short animated clips used by Richard Epp can be found at the PI website and can be downloaded for use in your classrooms. http://www.perimeterinstitute.ca/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/

Dinner with Richard Epp (PI Outreach). Elena Routledge, Heather Goodman Richard Epp, Spencer Richards, Jeffrey Highet, Katrina Pullia (missing: Hillary Geer)

Richard's enthusiasm for science was contagious. Our students continued to corner him after the presentation to ask questions. We would like to thank The Perimeter Institute for their generous support and Richard Epp's enthusiasm and patience. Our students found the experience memorable and many have already requested another USS Science TALKS.

Organizing an event does take time and planning. However, it did create an atmosphere that allowed our students to explore and question our universe for the weeks to come. Discussions exploded in our classrooms and students continued to do their own research to further investigate their own questions. It is through opportunities beyond the four walls of our classrooms that allow us to inspire our youth to question their own world and to seek out solutions to some of the world's most difficult problems that face us today. As we move forward into the next century, it is my hope that my role as a science educator is to inspire our youth to do great things. I do believe that teachers have a great power to influence, guide, inspire, encourage and challenge our youth to become The Great Thinkers of our future. Let's do this together!

Videos of Nonlinear Self-Organizing Phenomena

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Submissions describing demonstrations will be gladly received.

Many of the ordered structures that we see in the natural world are *self-organized* in the sense that they emerge spontaneously from the normal operation of the underlying laws of physics, but in a way which is not at all obvious from those laws, and with some regular order which is not due to external guiding forces. Ripples on the sand at the beach (Fig. 1) are an example: somehow the action of the turbulent waves on the individual grains conspires to form the ripples, a highly organized *patterned* state. The wavelength of the ripples is not at all obvious in the basic physics of water-sand interaction.

Figure 1: Ripples in sand.

Such phenomena are a rich source of fascinating physics, but are almost never discussed with undergraduates, much less high school students. They are almost always due to highly nonlinear feedback mechanisms which defy simple cause and effect theorizing. Despite much current research, their explanations are often contentious and elusive. But that only increases their attractiveness.

Meandering Syrup

If you dribble syrup or honey onto a pancake from a height, the syrup wraps itself into coils like a rope. But what happens if you move the pancake uniformly under the nozzle? It turns out that adding a translational motion *unfolds* the coiling into an interesting zoo of different states. In the following movie, syrup (Lyle's Golden Syrup works nicely) falls onto a moving belt, forming a device known as a *fluid mechanical sewing machine.* The belt continuously slows down, spanning a range of states from straight at high speed to coiling at low speed. These states are separated by abrupt *bifurcations* at which the form of the motion changes suddenly. The belt is 1 cm wide and the nozzle is a few centimetres above the belt.

Meandering syrup on YouTube:
http://www.youtube.com/watch?v=CMYISqxS3K4
Meandering syrup on Flickr:
http://www.flickr.com/photos/nonlin/3585645592/
Papers on this:
http://www.physics.utoronto.ca/nonlinear/papers_thread.html

Growing Icicles

Icicles are picturesque features of any Canadian winter. But what determines their shape? And why are some icicles covered with ripples? Remarkably, there is a theory stating that all icicles are isomorphic in overall shape that is, all icicles are rescaled versions of one another. In the physics lab at the University of Toronto we built an icicle growing machine to test this theory. We found that the theory is indeed upheld --- under certain conditions! The ripples, which are not included in the shape theory, are probably the result of a separate surface tension driven instability. They are observed to slowly climb up the icicles during growth. Given below are links to three time lapse videos of our experiment. In some runs, we rotated the icicle to encourage rotational symmetry. It takes about 10 hours to grow an icicle, and the rotation rate was once every 4 minutes, so it looks very fast in time-lapse but is actually quite slow.

A nearly ideal icicle on:
YouTube: http://www.youtube.com/watch?v=nfDdIFHmsc4
Flickr: http://www.flickr.com/photos/nonlin/4880941202/
A tap water icicle on:
YouTube: http://www.youtube.com/watch?v=Vx3zKpg4WLw
Flickr: http://www.flickr.com/photos/nonlin/4882839438/
Papers on this:
http://www.physics.utoronto.ca/nonlinear/papers_icicles.html

Washboard Roads

Anyone who has driven on gravel back roads knows they are anything but smooth. In fact, they quickly develop periodic bumps called *washboard road*. These bumps appear spontaneously above a certain threshold speed and, contrary to common opinion, are not simply related to the bouncing frequency of the suspension. Similar bumps, but with a smaller wavelength and amplitude, can even appear on the steel rails of Toronto streetcar tracks.

We built a lab version in which a wheel rolls around the circumference of a rotating table covered with a "road" made of sand. The wheel has no spring suspension; it simply falls on a lever under gravity. The washboard pattern moves slowly in the driving direction. There is a critical driving speed below which the flat road is stable, but it is too low to be a practical way to avoid washboard on real roads.

Youtube: http://www.youtube.com/watch?v=UHCJgh30kNE
Flickr: http://www.flickr.com/photos/nonlin/3597960161/
Closeup: http://www.youtube.com/watch?v=Hx7SHAlwR1Y

An even simpler version replaces the wheel with an inclined blade, forming a plough. The following is a stroboscopic movie in which the camera takes a picture once per table rotation, making the table appear stationary. In fact, it moves counterclockwise (seen from above), so the ripples move up rotation (i.e., clockwise or down the road in the driving direction). Notice how the ripple speed slows and the wavelength lengthens as the ripples grow to full amplitude.

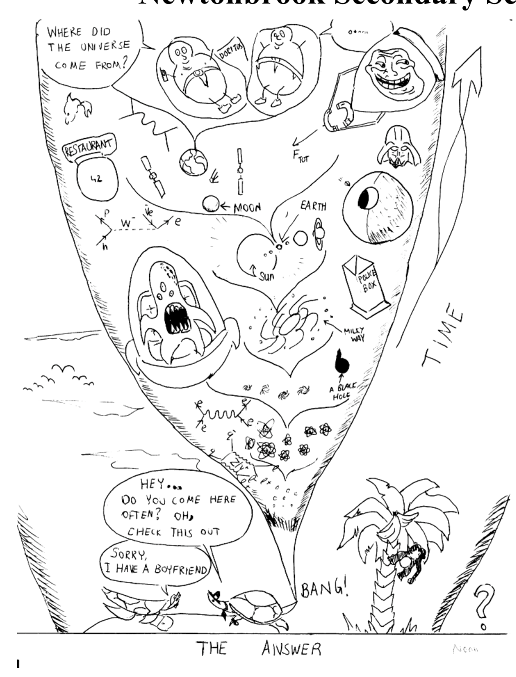
YouTube: http://www.youtube.com/watch?v=GduGTDWbc_M
Flickr: http://www.flickr.com/photos/nonlin/3663444274/
Papers on this:
http://www.physics.utoronto.ca/nonlinear/papers_sand.html

Students might enjoy reproducing these patterns, or observing them in the wild. For many other examples of nonlinear pattern formation, see

YouTube: http://www.youtube.com/user/smorris123
Flickr: http://www.flickr.com/photos/nonlin/
Homepage: http://www.physics.utoronto.ca/nonlinear/

There is also a wonderful series of books called Natures Patterns: a Tapestry in Three Parts, by Philip Ball: http://www.philipball.co.uk/naturespatterns.php

Cartoon By: Noam Sutskever
Newtonbrook Secondary School



P hysics Teacher: Tim Langfor d