A Solution to the Problem-Solving Problem

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This is the third 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

Problem solving ability is a set of skills coveted by students who do not possess it, taught often perfunctorily by high school physics teachers, expected of students by post-secondary instructors, and demanded by employers. In traditional physics instruction very little explicit instruction in how to go about solving problems is typically offered. This in itself is a problem to be solved! How might we nurture in our students the sophisticated problem-solving skills of the scientists, engineers and technicians who experts at solving problems? In this instalment of the PER Column I propose an approach that my students know as the "Physics Challenge": a context-rich, story-like practical problem requiring careful analysis, planning, teamwork, time management and the physical verification of the students' results.

Two skills associated with problem solving readily distinguish an expert from a novice:

1) the ability to quickly identify the relevant ideas and information (defining the problem), and
2) the ability to determine the *essence* of what is required to solve it (planning the solution).

Experts accomplish these tasks almost instinctively. Novice physics students typically struggle mightily with them. The Physics Challenge focuses on these oft-overlooked skills. Over the last seven years, I have built upon the work of Pat and Ken Heller from the University of Minnesota[i]. The Hellers developed an excellent structure for Cooperative Group Problem Solving (CGPS) that I modified for the high-school level and to which I have added my own empirical twist.

A typical Physics Challenge presents a group of students with a problem concerning a practical situation involving simple equipment. Its description uses everyday language, not physics terminology, to explain the scenario. Here is an excerpt from my favourite example, the "Washer Challenge":

Your group will be given a length of string, five washers and some tape. Your challenge is to attach the five washers such that when you release the string and the washers hit the ground, there is a steady sequence of sounds. This means a steady "clink-clink-clink-clink-clink." Not "clink, … clink ……... clink, clink, clink."

This is a real-world problem, not a mere academic exercise or trumped-up textbook problem. Several difficulties of the Washer Challenge are *implicit* in the wording of the problem and will likely become apparent to most students only after discussion with their group:

1) No measurements are given. The students must decide as a group what are the important quantities to measure;
2) Translation from colloquial language to physics terminology and symbols will be needed. For example, what do each of the two patterns of "clinks" as written above *mean* with respect to the physical quantities involved?
3) There is no obvious, quick solution. Physics Challenges are always multi-step problems and typically offer few overt clues pointing to a correct approach.

Considerable discussion and formal planning is crucial before jumping into the mechanics of solving a Physics Challenge. Few individual students would be able to solve one in the time allotted; the efforts of an organized group are required to succeed. To tackle these problems, the groups follow a series of general steps that help them focus on key problem-solving skills:

A. *The Picture:* Draw a clear picture, measure the important information and indicate it using symbols and simple descriptions;
B. *The Question*: Create a specific physics question that will give the solution to the problem;
C. *The Plan*: Identify key concepts, steps and equations that may be useful;

D. *The Work:* Choose and/or develop specific equations and algebraically manipulate them;

E. *The Results:* Calculate a final result, justify it and then physically verify it using the apparatus.

Three elements of the Physics Challenge – the style of problems, the structure of the problem-solving process, and the cooperative small group approach - combine to yield substantial improvements in students' understanding over traditional problem solving sessions. Adopting the Physics Challenge system does involve a learning curve for the teacher as well as for the students, but the outcomes it produces will greatly reward the teacher who invests the energy and takes the plunge. For examples of more problems, please download the package of teacher resources[ii] available from my website. For a presentation introducing cooperative group problem solving and a sample solution to the Washer Challenge, please download my active learning course [iii]presentation. Good luck!

[i] This is an excellent starting point for any teacher interested in learning more about these techniques: http://groups.physics.umn.edu/physed/Research/CGPS/CGPSintro.htm

[ii] http://meyercreations.com/Physics/PER%20Gr12.htm

[iii] http://meyercreations.com/Physics.htm

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Moving to the other side of the desk: One physics teacher candidate's experience

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Making the transition from being a physics student to being a high school physics teacher is a challenging yet very rewarding endeavour. As a teacher candidate at Queen's University, I've been in the (somewhat painful) process of tackling the many challenges involved. I'm sure all readers of this article remember the very first time they switched to the other side of the desk and the feelings that went along with that transition. *Excitement* was what I felt the most. (Of course, it could have been nervousness in disguise…). Some months later, I now find myself stumbling less and less with each passing week. I'm glad that I still feel excited as I look ahead to my final four-week practicum.

I have been privileged to have a great deal continuity between my educational theory classes at Queen's and my practicum experiences. This and the creative freedom to explore different ways that physics concepts can be taught have helped me immensely. My first associate teacher's attitude that "anything can be fixed, so don't worry" may have been the single most important motivator for me so far. That simple reassurance that taking risks and making mistakes is okay has speeded my learning and my progress towards success as a teacher candidate.

In my first eight weeks of practicum I got the chance to teach both the Waves and Sound and the Forces units in Grade 11 Physics. I followed Knight's *Five Easy Lessons: Strategies for Successful Physics Teaching* closely and made it my main source of strategies for addressing misconceptions the students brought to each topic. The most rewarding moments during my practicum came when students experienced demonstrations that conflicted with their previous conceptions and left class with a new view of their world.

It has been a great start to what I know will be an extremely rewarding and exciting career. I'm starting to gain traction, and I'm starting understand what education is really about.

What's Up Down in SNOLAB?

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Thumbs up from 2 km underground!

"Sudbury is the perfect place to study snow!" asserted my aunt when I announced that I was coming to my hometown to present one of Perimeter Institute's *Search for Dark Matter* workshops. Confused, I agreed. But then she asked why I would arrive in early November "because we don't get much snow until December". Smiling to myself, I patiently explained that SNOLAB (Sudbury Neutrino Observatory LABoratory) is getting a face lift and that this would be a wonderful opportunity to visit all the experiments while the apparatus was being renovated and expanded for further underground particle astronomy. "Oh!" said she…

35 teachers from northern Ontario attended the Perimeter Explorations Session hosted by Samatha Kuula, Education Outreach Officer for SNOLAB. Where better to attend such a workshop than the world's deepest physics laboratory!

Arriving at 0600 h, we were hurried into underground mining gear after signing multiple waiver forms. We caught "the cage" in the active *Vale-Inco* Creighton mine to report for our 2.0 km descent into the Earth's crust. This rather jerky three minute experience was followed by a 1.5 km walk through the dimly lit horizontal shafts before arrival at the SNOLAB facility. The first and most essential order of business was taking a water and air shower and donning *Tyvek* clean wear. Having just walked 1.5 km through one of the world's dirtiest environments, we emerged into one of its cleanest: the heart of SNOLAB.

Since SNOLAB's success (2001-2006) in empirically proving that solar neutrinos come in three flavours (electron, muon and tau) that can interchange spontaneously, the facility has undergone a huge renovation. The original SNO project had ended, but the available space for research into the constituent make-up of dark matter has been more than tripled. Many new international experiments are being housed in the cavernous facility, shielded from cosmic rays by over two kilometres of norite overburden.

Dr. Chris Jillings, a staff scientist at the facility, was our expert guide for a tour of the experiments and the specialized environmental systems that support them. Since SNOLAB is a self-contained environment, it includes a bioregenerator as well as highly sophisticated water distillation, air purification and chilling systems. Only about 5% of the matter in the universe is visible matter while five times that amount is dark (or non-baryonic) matter. Dr. Jillings showed us, and described in detail, the dark matter experiments taking place in SNOLAB. He himself is involved in **DEAP-1**: the Dark matter Experiment with Argon and Pulse-shape discrimination. The world famous **PICASSO-1** experiment continues to run concurrently with DEAP-1, and there are plans for new, larger, experiments: **DEAP3600** and **miniCLEAN** (for details visit **http://www.snolab.ca/public/experiments**).

Jillings and Dr. Christina Kraus of Laurentian University also took the time to walk us through the former SNO (now called SNO+). Here a new scintillation technique using an alkylbenzene compound is has been designed to detect the poorly understood neutrinoless double beta decay. The goal is to determine whether neutrinos are Majorana particles (where the neutrino is its own anti-particle) or Dirac particles (with distinct particle and anti-particles). The neutrino has become a major suspect in the "Mystery of the Missing Matter". Our current understanding of the Standard Model suggests there ought to be a fine balance between matter and antimatter. Since observations show a heavy asymmetry towards matter, accounting for only a small fraction of the mass in the universe, scientists have been studying the neutrino, which interacts only through the gravitational and weak forces. The dark matter experiments are designed to detect WIMPS (Weakly Interacting Massive Particles), a postulated exotic particle that would interact only through the gravitational force. The difficulty with these delicate experiments is that all the evidence is indirect and circumstantial. By a process of elimination of other known processes, the mystery will be eventually revealed.

Re-donning our mining gear, we walked back to the cage while grilling the about the nature of reality, the proofs for the Standard Model and the state of research physics in Canada. My workshop needed to be cut short, as we had not foreseen that our first prolonged underground excursion would lead to widespread exhaustion amongst the participants. Dr. Nigel Smith, the director of SNOLAB, summarized current global efforts in astroparticle physics, including his own research at the soon to be completed IceCube neutrino detector in Antarctica. Dr. Smith left us with the many major questions that researchers at SNOLAB are seeking to answer:

- *What is the physics beyond the standard model?*

- *What is the nature of the neutrino?*
- *What is the mass, and mixing parameters, of the neutrino?*
- *How do stars 'burn'? How do stars explode?*
- *Where does the heat of the Earth come from?*
- *Where does the matter-antimatter asymmetry in the Universe come from?*
- *How do fault slips develop?*
- *How does life evolve in extreme environments?*
- *How do the most extreme astronomical events evolve?*
- *What constitutes most of the mass of the Universe?*

To have a virtual experience of our tour, watch the 8-minute long "Neutrinos Uncovered" on YouTube: http://www.youtube.com/watch?v=WE565jXuVuM

The Demonstration Corner

QuickTime™ and a decompressor are needed to see this picture.

GPS Meets Einstein

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Submissions describing demonstrations will be gladly received.

Column Editor's Note: *The author of this article presented a fascinating talk about this topic at the 2010 OAPT Conference. Via the weblink provided in the article, readers can obtain access to a very useful student activity that demonstrates the importance of relativity in the operation of GPS.*

The Global Positioning System (GPS) is one of the twentieth century's greatest engineering marvels. Today, it's the backbone of billions of dollars of economic activity. It's used by a vast array of occupations including farmers, construction workers, doctors and even professional athletes. And all this comes on top of the more familiar personal applications like satellite navigation in cars and for hiking.

As well as being immensely practical, the GPS also involves some pretty cool physics — even, strangely enough, Einstein's theory of relativity.

The GPS is based on network of 30 or so satellites that continually send out ultra-precise timing signals in the form of radio waves. By picking up a signal from one satellite, you can calculate your distance d from the satellite via the equation $d = v\,\Delta t$, where v is the radio wave's speed (the speed of light) and Δt is the time the wave takes to get from the satellite to you. Repeating this process for four satellites, you can pinpoint your location anywhere on Earth to within a few metres. To me, this level of accuracy is simply amazing.

But, where does relativity fit into the picture? The concept of *time dilation* in special relativity says the faster the speed of an object (relative to an observer), the slower the observer measures the object's time as passing. Interestingly, *general* relativity — Einstein's theory of gravity — also tells us there's another type of time dilation, one based on gravity. *Gravitational time dilation* says that the strength of a gravitational field affects the rate at which time passes. Clocks in weaker gravitational fields run faster than clocks in stronger fields.

Each GPS satellite houses a state-of-the-art atomic clock capable of measuring time to within a fraction of a nanosecond. The timing of the GPS signals is so precise, the system needs to take both types of time dilation into account for the GPS to work. The effects are tiny, just 7 microseconds a day from special relativity and 45 microseconds a day from general relativity. However, if these numbers are substituted into the equation $d = v\,\Delta t$, you get distances of 2 km and 12 km respectively over the course of a day[1]. That's more than enough to render GPS navigation completely useless if relativity is not properly factored in.

The GPS takes relativity into account by offsetting the timing of the atomic clocks slightly to compensate for the effects of time dilation. To me, this is a beautiful example of the usefulness of modern physics.

To help highlight the link between the GPS and relativity, Perimeter Institute has created a new classroom resource on the topic. "Everyday Einstein: GPS and Relativity" has a five-minute in-class video along with a 20-page teacher's guide. The guide includes extra information for teachers and five student worksheets and activities. Everything can be found on Perimeter's website at: http://www.perimeterinstitute.ca/en/Perimeter_Inspirations/GPS_%26_Relativity/GPS_%26_Relativity/

Teachers from across Canada can also order a physical copy for free from PI's website. I hope people find it a useful addition to their classrooms.

[1] To get the results 2 km and 12 km, you need to multiply the distances results by the number of seconds in a day, 86,400