Pedagogical Design

Compiled by David M. Harrison, February 2005. Last modified March 21, 2005: new section at the end on de-mystifying computerized data acquisition; reference the new Lab Equipment document; reference the new Formal Report Module.

Introduction

Particularly in the last decade *Physics Education Research* has taught us a great deal about how students learn. Among the lessons are:

- In a traditional introductory Physics class, at the end of the year most students still have many wrong ideas about the fundamental concepts of the scientific description of the physical universe.
- Most students learn most effectively in a social context. This is very different from the learning strategy many academics prefer, which is to find a quiet corner and to “wrestle” with the textbook or journal article.
- Conceptually based activities using a *Guided Discovery* model is the single most effective strategy in helping students to understand the fundamental ideas of Physics.
- Interactive activities in the classroom in place of the traditional lecture are also very effective in aiding student understanding.
- When students understand the fundamental ideas, their ability to solve traditional numerical problems is also improved.

Here we propose using these lessons for a fundamental redesign of the tutorial and laboratory structure of our first year Physics courses. We propose combining the tutorials and laboratories into a new series of *Physics Practicals*.

The courses that are particularly targeted are:

- PHY110Y – Basic Physics – 370 students.
- PHY138Y – Physics for the Life Sciences I – 1130 students.

Other first year courses currently being offered by the Department are:

- PHY140Y – Foundations of Physics – 150 students.
- PHY180F/PHY181S – Elements of Physics – 320 students. (This is for Engineering Sciences students.)

- PHY100F/PHY100S/SCI199Y – largely non-mathematical courses currently without an associated laboratory.

The role of these courses in the redesigned Practicals is still under discussion. Extending some of these materials to our non-mathematical courses is a particularly intriguing idea. However, here we restrict the discussion to PHY110 and PHY138.

Also not discussed here is propagating this new pedagogy into the upper-level Physics courses.

We intend to invite our colleagues at UTSC and UTM to become involved in this project.

Although we are calling this project *University of Toronto Physics Practicals* (UTP^2), many other Canadian undergraduate physics courses are also beginning to implement these new teaching techniques. We have discovered that U.S.-developed materials using this pedagogy are too simple for Canadian students. Thus the materials that we develop may be of use at other Canadian universities, and we intend to invite these universities to participate in the development. Involving secondary school teachers could give us added information on the background of our students.

Current Tutorials and Laboratories

In addition to "lectures"[1], every week students meet in groups of approximately 25 for one hour tutorials. Every second week the students meet in groups of approximately 14 for a three hour laboratory.

This year PHY138 has implemented some activity-based materials in its tutorials. These were fairly successful, although work still needs to be done on finding materials at an appropriate level for our students. PHY110 tutorials are more traditional problem solving sessions.

Another issue with activity-based tutorials in PHY138 is that many of the rooms that are used are not appropriate for the small-group collaborative work which is the heart of this method. Instead, rooms are designed for small lectures and the furniture may not be easily moved into a more suitable configuration.

PHY110 and PHY138 take the same laboratory. Designed over 30 years ago, educationally it is conceived as totally separate from the lecture component of the courses. Thus, it is virtually a separate course teaching *Experimental Science*.

When the lab was designed, students were more willing to accept learning for its own sake than our current classes. Thus for many years it was a popular laboratory, rated by its students as the best of all the science labs that they were taking. Now students are

[1] I am trying to drop the word "lecture" from my vocabulary.

much more goal oriented than their predecessors, and the evaluations of the laboratory are far from what we would like.

Neither current tutorials nor laboratories are taking full advantage of new and proved educational methods. This proposal addresses this lack.

The New Physics Practicals

We intend to combine the tutorials and laboratories into a single Physics Practical. These will meet every week. Currently in every 2-week cycle the students attend 2 hours of tutorials and 3 hours of labs. If the Physics Practicals have a duration of 2.5 hours per week, student load will be unchanged.

Each Practical group will consist of up to 32 students, under the supervision of two instructors. The group will meet all year with the same instructors, and at least initially will be meeting in the same room every week.

The new Practical rooms are purpose-designed. The design, discussed elsewhere, is maximally flexible, and therefore does not lock us into the educational purposes discussed here. Since the new Practicals will replace existing tutorials, the rooms currently used for these may be used by the University for other purposes.

We may classify the Physics Practicals into two broad categories:

1. *Conceptual*. These concentrate on the concepts at the heart of what is currently being discussed in the students' class.
2. *Discovery*. These are designed for experimental investigation of topics that are not directly related to the topics of the classroom.

We will now discuss these in more detail.

Conceptual Physics Practicals

The topics of Conceptual Physics Practicals are those currently being discussed in class. Thus, modules could include investigations of:

- Mechanics
- Waves
- Optics
- Heat
- Electricity and Magnetism
- Nuclear Physics and X-rays

During the Practical, the module will be investigated by a group of 4 students, who work together as a team. Often the module will involve real physical apparatus, typically connected to a computer and data acquisition hardware. Other times computer simulations will be more appropriate. There may also be modules that only require paper and pencil.

Some modules may be all or nearly all qualitative. Others will be much more quantitative. All modules emphasise basic concepts.

In all cases, during the sessions the students are expected to construct answers for themselves through discussions with their classmates and their instructors.

Two particularly important issues in the development of these modules are:

1. Course tests and examinations must include qualitative questions that emphasise the concepts and reasoning skills developed in the Practical.
2. The materials are developed taking account of the fact that the instructors are typically graduate student Teaching Assistants, who may well not have a good understanding of the concepts being developed.

This type of Physics Practical will be used almost exclusively for at least the first half of the academic year. Since they should track the material discussed in class, the current module may differ for different courses.

For a particular course for a particular week, ideally we would have enough setups for all students to be doing the same module. Certainly, we will need enough setups for one half the students. In this non-ideal case, in a 2 week span all students will have done the same 2 modules. Say we have 2 modules, M1 and M2, on the current topics of the classroom. Then one week one-half the students will do M1, the other half M2; the following week the students will go through the other module.

Discovery Physics Practicals

In the second term we will introduce Discovery Physics Practicals, which investigate topics in Physics which are probably not covered in the classroom. The investigations will in all cases be experimental, not theoretical, and be based on real physical apparatus.

Here the students could work in pairs. [Think more about this. Implementing projects such as suggested by John Sipe could work well with groups of 4 students.]

The transition from Conceptual to Discovery Practicals will be accomplished by modules specifically designed to introduce the students to the topics of record keeping, data analysis, and error analysis.

The topics of subsequent Discovery Practicals will drawn from our existing 40 different experiments, and we will give the students free choice of what experiment they wish to perform, subject to availability. During this phase, the students in a particular group will no longer necessarily be doing their Practicals in the same room.

Assessment

Priscilla Laws at Dickinson College in Pennsylvania is fond of saying "If you don't test for it, you don't get it." Above we stressed the importance of including material from the Concept Practicals in course tests and exams. However, we may wish the Practicals to generate their own marks to be included as one component of the final course mark.

For Conceptual Practicals, it is tempting to introduce a pass/fail marking system where to achieve a pass requires that the student attend and participate in the Practical. At Sydney University, Australia, attendance at their "Interactive Workshop Tutorials" is optional and no marks are awarded; over 80% of their students attend more than two-thirds of them.

For Discovery Practicals, we intend to continue using our computer-delivered test on error analysis for one component of the mark. The remainder of the mark could be from a traditional marking of their experimental work, or could also be pass/fail. In the latter case, some of the material will need to be explicitly included on class tests and exams. Below in the *Formal Report* section we mention that we also want the students' formals to be marked in detail.

Implementation

This project will require significant resources to implement. The physical plant requirements are non-trivial, and a very preliminary document on this exists. There is also a rough estimate of the lab equipment costs available.

We think it is vital that the renovations in the physical plant occur simultaneous with the major part of the development of the Practical modules. Doing the physical plant first and then later implementing materials to use the new environment sounds like a prescription that will end up with shiny new lab rooms and, as enthusiasm wanes, the same old things are done in them.

Implementing the modules will require significant monetary resources for equipment. However, the major cost will be in human resources.

[This needs considerable thought ending up with some numbers. Laws says it took her five years. Despite the fact the U.S.-based materials from McDermott, Laws, Mazur, Redish et al. are generally too simple for our students, we can certainly build from much of their work.]

Formal Reports

Not mentioned above but nonetheless important is the issue of scientific communication. Whole course can be (and in some cases have been) mounted on this topic. One plan could involve having the students individually do one Formal Report on an experiment that they have performed. They then bring the first draft and the small-group of 4 all discuss each other’s reports. The individual student then goes off to produce a final draft of their report, which is turned in to be marked. A draft of the Guide for the students of this Module exists.

About Computerised Data Acquisition

It is almost certain that many Modules will involve computerized data acquisition. We should be sure to de-mystify this process when the hardware and software is first introduced. The first Module using this apparatus could well be on kinematics. Then we could have students estimate each other’s speed while walking. Then we have the students use the motion detector to measure their walking speed.

In a later module, we could de-mystify the motion detector further by measuring the sound wave that it emits. This could be part of a unit on echo location. We have a prototype experiment dealing with this topic.

This issue is discussed in: William P. O’Brien, Jr., “Deconstructing Black Box Aspects of a Computerized Physics Lab,” Physics Teacher **43**, 148-152 (2005), although he is talking about electrical measurements.