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# A practical application of Physics Education Research-informed teaching interventions in a first-year physics service course

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# A practical application of Physics Education Research-informed teaching interventions in a first-year physics service course


### Abstract

First-year physics service courses across North America typically face similar problems, such as the lack of math preparation of the incoming students, or the perception by the students that the course content is irrelevant for their future studies. It should be described how to apply changes informed by Physics Education Research, in particular the labatorial model, to such a course on a short time scale and under tight practical constraints. Examples for student activities are given, and the observations, challenges, and anticipated long-term benefits for the students as well as the department are pointed out.


*Keywords:* Physics Education Research, First year service course, Labatorials

### Ein Praxisbericht zur Anwendung von *Physics Education Research* in einer Einführungsvorlesung


### Zusammenfassung

Typische Probleme für die Einführungsvorlesungen in Physik an nordamerikanischen Hochschulen, speziell in den Serviceveranstaltungen, sind die unzureichenden Mathematikkenntnisse der Studierenden sowie ihre Überzeugung, dass die Vorlesungsinhalte irrelevant für ihre weiteren Studien sind. Hier wird beschrieben in welcher Art und Weise man praktische Strategien, basierend auf den Erkenntnissen der Physics Education Research, anwendet, um diese und verwandte Probleme anzugehen, in einem engen zeitlichen Rahmen und mit begrenzten Möglichkeiten bezüglich Budget, Räumen und Ausstattung. Es werden Beispiele für die Aktivitäten vorgestellt und Beobachtungen beschrieben; außerdem werden die zu erwartenden Herausforderungen und Erfolge für die Studierenden und die Lehrenden definiert.


*Schlüsselwörter:* Physics Education Research, Einführungsvorlesung, Labatorials

## 1 The Background: First-Year Physics Service Courses in North America

Many universities in North America offer two or three different first-year physics courses for different types of students: The introductory course for physics majors, often including the engineering majors, needs to lay a solid foundation for the whole program, including the use of calculus. The course for arts students typically does not require any mathematical knowledge and is largely descriptive, often focused on „easy“ topics such as astronomy. In between these two extremes lies the service course for science (e.g. biology or geoscience) majors, which is often a „dumbed-down“ version of the course for physics majors in that it covers the same content, but to a lesser depth and using algebra instead of calculus.

This type of service course is typically very unpopular, even feared, among the students: They lack the necessary mathematical skills, and they do not see the relevance of the course content for their future studies. These students often have a distorted view of physics as a random collection of facts, and they have „learned“ that success in a science class is achieved by memorization, not understanding of concepts (see, e.g. Redish, Saul & Steinberg, 1998). It does not help that many of the teaching assistants for these courses, physics graduate students, are new to North America and unfamiliar with the student population as well as the standards to be expected.

Fortunately, there exists a large body of knowledge accumulated by Physics Education Research (abbreviated PER in the following) over the past three decades that can be used to improve teaching and learning in courses like this. In this paper, a description will be given, how PER-informed instructional materials and methods were designed and used to enhance students learning in a first year service course. The goal is to illustrate what can be achieved on a short time scale, despite tight practical constraints (time, budget, rooms and equipment), what difficulties are to be expected, and which long term benefits are anticipated for the students, the teaching assistants (abbreviated TAs in the following) and the department.

### 1.1 Physics Education Research – A Very Brief Overview

Physics Education Research in North America studies teaching and learning at the University level, with an emphasis on first year, because these are the courses that not only affect the largest numbers of students, but also constitute bottle necks for their future careers. Researchers typically have a background in physics and are often embedded in or supported by physics departments, such as the Physics Education Research groups at the University of Maryland and at the University of Washington. A main goal of PER is to develop evidence-based teaching materials and strategies to improve students learning capacity (an extensive overview can be found in the Resource Letter by Meltzer & Thornton, 2012), and to „measure“ the effectiveness of those materials and strategies (an approach sometimes called „Scientific Teaching“) using pre- and post-tests such as the FCI (Force Concept Inventory) (Hestenes, Wells & Swackhamer, 1992), attitude surveys such as CLASS (Colorado Learning Attitudes about Science Survey, developed by the Physics Education Research Group at the University of Colorado), or interviews. Another main goal of PER is research why students learn – or don’t learn – physics. This includes research on student misconceptions in various areas of physics (see, e.g. McDermott & Redish, 1999) as well as using results from general education research, psychology, neuroscience, sociology, or linguistics (see, e.g. Redish, 2003). Very briefly, the results that are most relevant for student learning in first-year service courses can be summarized as follows:

1) Content: Students enter introductory physics courses with misconceptions about the physical world as well as about learning (i.e. their minds are not a „blank slate“) that need to be confronted and resolved.

2) Teaching Strategies: Traditional passive learning environments are not very successful in overcoming these misconceptions and should be replaced by active learning environments.
3) Assessment: Students often do well on traditional textbook style problems without actually understanding the concepts. Problems of a different type are needed to show the students as well as the instructor how well they understand the underlying physics concepts.

Examples for the teaching materials and strategies based on PER are Physics by Inquiry, developed by Lillian McDermott and collaborators at the University of Washington, or Workshop Physics developed by Priscilla Laws at Dickinson College, which were among the first projects, the now widely used Studio Physics or Peer Instruction by Eric Mazur, or the more recent Labatorial project at the University of Calgary (Ahrensmeier et.al., 2009). Many practitioners with knowledge about PER will also try 'ad-hoc solutions' while they are teaching (sometimes called „continuous improvementor" or „action research"), which may turn into more rigorous research projects later. This might be motivated by the science background that most people in PER have (a natural inclination to do experiments), but also by the extremely limited availability of funding for rigorous Physics Education Research, especially in Canada (see, e.g. Antimirova, Goldman, Lasry, Milner-Bolotin, & R. Thompson, 2009).

## 2 The Course and the Educational Goals

In spring of 2013, the author taught PHYS 101 at Simon Fraser University. This course covers basic Newtonian mechanics, from kinematics to rotational dynamics and fluids. It is required for life science students and recommended to be taken in their first year, although many students defer it until fourth year. The course consists of three lecture hours per week (large auditorium, ca. 200 students, most instructors use demonstrations and clicker questions), one hour of tutorial per week (taught by TAs, up to 24 students per section), no laboratories, and weekly online homework assignments (using a commercial product, Mastering Physics, www.masteringphysics.com). Marks are given for the tutorials (10%), the homework (10%), the clicker questions (5%), two midterm exams (15% and 20%) and the final exam (40%).

Since this is a service course, the educational goals are slightly different from those for a course for physics majors: Students are expected to gain a better understanding of the basic physics concepts, a better understanding of the relationship between the phenomena and their various abstract representations (models, graphs, data, equations), improved 'problem solving skills[1]', an improved attitude towards physics, and improved communication skills with respect to science content.

[1] This is actually the goal mentioned most often by Life Science faculty.

## 3 The Practical Constraints and the Solutions chosen

Traditionally, many first-year service courses in physics have been taught with the assumption that students will somehow understand the „big picture“ and the underlying physics concepts by listening to a lecturer, performing cookbook-recipe labs and solving traditional textbook problems. Research has shown that this assumption is not justified (see, e.g. Meltzer & Thornton, 2012). Instead, it is crucial to align the educational goals for the course with the choice of content, the teaching strategies and the assessment methods. The method being used for the Course Design Workshops at SFU follows the model of Rethinking Teaching in Higher Education, as described in Saroyan and Amundsen (2004). The author tried to follow these principles as much as possible under the given constraints.

Table 1 shows how the various components of the course content support the educational goals („Physics“ refers to the bulk of the course, the actual physics content). For example, pointing out explicitly the transferable skills the students are supposed to learn makes them realize, how important it is to practice their writing skills, something that most of them did not expect for a science class.

| | Course Content | | | | |
|---|---|---|---|---|---|
| | Real World Examples | Physics | Transferable Skills | Epistemology | Calculus |
| Problem Solving | ✔ | ✔ | ✔ | ✔ | ✔ |
| Physics Concepts | ✔ | ✔ | | ✔ | ✔ |
| Communication Skills | ✔ | | ✔ | | |
| Representation Methods Literacy | ✔ | ✔ | ✔ | | ✔ |
| Attitude | ✔ | | ✔ | | ✔ |

Tab. 1: How the various elements of the course content address the educational goals

Table 2 shows how the teaching strategies (tutorials, clicker questions, online homework, lectures) and the assessment methods (tutorials, clicker questions, online homework, exams) are aligned with the educational goals. This table reveals an issue typical for this type of course: The teaching strategies that are best aligned with the educational goals, in this case the tutorials and the clickers, are not the ones taking up most of the time. The teaching strategies that dominate the time spent by the instructor and the students, the lectures and the homework, address only some of the educational goals. Since a redesign of PHYS 101 is planned for the near future as part of a larger redesign project, further optimization of this alignment will have to wait a little while.

| | Teaching and Assessment Strategies | | | | |
|---|---|---|---|---|---|
| | Tutorials | Clicker Questions | Online Homework | Lectures | Exams |
| Problem Solving | ✔ | ✔ | ✔ | ✔ | ✔ |
| Physics Concepts | ✔ | ✔ | ✔ | ✔ | ✔ |
| Communication Skills | ✔ | ✔ | | | ✔ |
| Representation Methods Literacy | ✔ | ✔ | ✔ | ✔ | ✔ |
| Attitude | ✔ | ✔ | | | |

Tab. 2: How the teaching and assessment strategies of the course address the educational goals

### 3.1 Course Content

Since a service course of this type is often a simplified version of the course for physics majors, for historical reasons, the course content is not optimized for the needs of Life Science students. In some cases, courses like PHYS 101 have been redesigned to include more of the topics that are relevant to the biological sciences, but these redesigns are rarely sustainable, because they are tailored to a specific instructor and his or her expertise. It is therefore crucial to redesign these courses in a way that allows them to be taught by any instructor in the physics department.

When thorough redesigning is not possible, for example because the course is a prerequisite in other programs who do not want to see the content changed, a solution that some instructors choose is to include many examples from the life sciences. Some students find that these examples make the course more relevant for their future studies, while others find that they add an unnecessary level of complexity. However, examples alone don't address a fundamental issue that is only starting to emerge in the literature in the past few years (see, e.g. Redish & Hammer, 2009), the epistemological differences between physics and biology: Simply put, physics reasoning is based on fundamental principles and uses concepts like toy models or limiting cases which often seem unintelligible to life science students. Biology deals with complex systems that cannot easily be reduced, is often descriptive and less quantitative. These fundamental differences are usually not addressed explicitly, which adds another reason for students to find physics hard to understand.

Another topic that is pointed out more and more by colleagues of the life sciences is the increasing use of quantitative methods in their fields, and therefore a need for better math skills, which is often surprising to students who chose a „soft“ science with the intent to avoid the „hard“ mathematics.

These considerations lead to an explicit accentuation of epistemological issues (to enhance the students’ understanding of physics as a scientific theory) as well as the transferable skills that students are expected to learn during the term (to illustrate an unexpected aspect of how this course will benefit them in the future), the latter simply included in the course schedule. Instead of including examples from biology, some „real –world- examples” were used (which can be designed to address all the educational goals) and to exclude examples that are of very limited value to life science students, such as collisions (an easy way to improve students’ attitude). Students were also gently exposed to the use of calculus, which is not a pre- or corequisite for this course, by showing them how it can make their lives easier and how it is related to what they learn in their math classes.

## 3.2 Teaching Strategies

The format of the course, with three hours of lectures and one hour of tutorial, can currently not be changed due to scheduling restrictions. A good way to introduce some interactive elements in the lectures is the use of ‘student response systems’ (clickers). The use of clickers in large physics classes is by now standard in North America, and many studies of their effectiveness can be found in the literature.

The most dramatic change in the course delivery was the redesign of the tutorials, accompanied by TA training. Traditionally, the learning activities in the tutorial session depend on the instructor’s preference and range from a traditional recitation to a drop-in session in which students try to get help with their homework. To enhance the effectiveness of this valuable one hour during which students have contact with a TA, new tutorial worksheets were designed, following the labatorial model that a group of colleagues and the author developed, tested, and implemented at the University of Calgary between 2008 and 2012.

### *3.2.1 Background: The Labatorial Model at the University of Calgary*

The labatorials were introduced as a redesign of the small group sessions (tutorial and/or lab) of first year physics service courses at the University of Calgary. Those courses are of the same type as PHYS 101, only bigger (ca. 1000 students, taught in 4-5 sections), but they dealt with the same issues as those described in the introduction.

A set of 9 or 10 labatorial worksheets for the weekly sessions of each course was developed by this group of scientists, based on results from PER: Each worksheet addresses typical misconceptions on one specific topic, which has been covered in class before the labatorial. The activities for the students are tailored to that topic and include mini-labs, simulations, analyzing videos, doing calculations, answering conceptual questions, drawing and analyzing sketches or graphs etc.

The students work through the worksheet in groups of four. Each student is responsible for writing down the results on his or her own worksheet. When they reach a checkpoint, marked by a stop sign on their worksheet, they call the TA over to check their work. The TA discusses the work with the group and tries to make sure that they do not just have the right results, but also understand how they got there, and why it is right. While the TA is only supposed to check one randomly chosen student's write up, the other students are responsible to correct or add to their own notes, if necessary. If more than a few little improvements are required, the TA tells the students what they need to do. When everything is satisfactory, the TA checks off this part of the worksheet, and the group moves on to the next. Each worksheet is designed so that an average group of students can finish it in their two (or three, depending on the course) hour time slot, assuming they are up to speed with the course content and keep focused.

The checkpoint system has two big advantages: The students receive feedback on their work right away, while their minds are still occupied with the topic. Since there is no marking of lab reports required, enough TA time is freed up to increase the ratio of TAs to students by a factor 2, which is necessary to provide quality teaching with this format (we found that a ratio of 1 TA for 12 students is necessary to give the TAs enough time to properly check the students' work and provide feedback).

This kind of teaching requires well prepared TAs, which is the reason why we introduced weekly mandatory training sessions. In these training sessions, the TAs work through the labatorial worksheets just like the students, in groups, and an instructor or postdoc who designed the labatorials serves as their TA. This gives the TAs the opportunity to experience first hand the problems that students may encounter, both with the equipment and with the problem solving. Then, the TAs discuss misconceptions and questions they anticipate, and how to deal with them. They also clarify with the trainer what level of understanding they should aim for and discuss time management and general teaching strategies.

Some of the observations and findings are described in Ahrensmeier et al. (2009) and Ahrensmeier, Thompson, Wilson and Potter (2012). Most importantly, it could be proved that the typical student questions changed from „Is this correct?“ to questions aimed at understanding. An improved attitude towards physics could be noticed, student groups were often having fun doing their labatorials. From written student feedback, the conclusion was possible that the labatorials helped students realize early in the term that they had to „actually study“, as some of them worded it, to be successful – something we had not expected, but certainly useful for the students. Most of the TAs prefer this way of teaching to the traditional way of running tutorials or labs, they enjoy interacting with the students and „actually seeing them learn“, as some of them described it.

Of course, these positive effects did not materialize immediately. In the beginning, many students objected to having a more active role as required by the inquiry-based worksheets, and most of them felt overwhelmed by questions that don't have a single correct answer. Many TAs were uncomfortable with the idea that students would receive full marks on this part of the course by just „being there and doing the work“. It took about a year for the mood to start changing, and three years to see a substantial culture change. Now, many TAs explicitly request to be scheduled for this type of course, and their reputation among students has improved.

### *3.2.2 The Tutorials for PHYS 101*

The tutorial worksheets for PHYS 101 were designed as mini-labatorials, due to some practical constraints: The time slot is only one hour long, instead of two or three, and the rooms cannot be equipped with any actual experimental equipment or computers for data collection. Instead, the students had to use their laptops and household items for little experiments.

The tutorial worksheets were designed to address the educational goals for the course as well as possible: They probe and reinforce the conceptual understanding with conceptual questions, and they require the students to answer questions in full sentences, even paragraphs. Instead of the „plug and chug“ questions often found in textbooks, the worksheet problems explicitly ask the students to use various representations of the physical phenomenon, including a sketch before they even start calculating. A good example is Question 1 below, which is the first question on the first worksheet, setting the tone for what to expect in the tutorials:

> *Question 1: As a warm-up for their juggling act, two clowns are tossing balls straight up in the air and catching them. While following the balls with his eyes, Joey says, „Isn't it strange how they just stand still in the air for a moment before they fall back down?“ „Nonsense“, says Charlie, „they never stand still, it's just that there is no acceleration at the top of the path.“*
>
> *a) State whether Joey is right or not, and explain why. Include a sketch in your explanation.*
>
> *b) State whether Charlie is right or not, and explain why. Include a sketch in your explanation.*

To hone their problem solving skills, students are given real world situations, which means they don't have an „algorithm“ available for solving this type of problem. They also may have too much or insufficient information, which means they have to make reasonable estimates or do some research, as for Question 2 (taken from a different worksheet):

Fig. 1: A ski jump built by students in Norway (image from www.panoramio.com/photo/15907314).

Question 2: Students in Trondheim, Norway, have built a ski jump ramp that starts at their kitchen window.

a) From the photo, estimate how far they can jump from this ramp, ignoring friction.

b) Now watch the video of an actual jump on youtube [link provided]. Does your result agree with the distance in the video? If not, what could be the reason?

The examples and especially the little experiments for the tutorials are chosen with the intent to also provide some entertainment, to address the attitude issues many students have with physics. An example is question 3, from yet another worksheet:

Question 3: Your task is to design and perform a little experiment to determine the coefficient of static friction between the surface materials of two objects that you have with you, such as a pencil case and a binder, or a small pad of sticky notes and your laptop. Hint: Look at figure 4-28 in your textbook to see in which physical situation this coefficient plays a role.

a) State which two objects you will be experimenting with.

b) Describe your experiment, including a sketch.

c) Which variable(s) do you think you will need to measure?

**Checkpoint**

d) Draw the free-body diagram for your experiment. Make sure that the angles and the lengths of the vectors are correct. Label forces and angles that you may need for your calculation (use your coordinate system wisely!). Then, express the components of the forces using the angles.

e) Write down Newton's second law for both x- and y- components. Simplify and use the expressions you found in part (a).

f) Write down the condition for the physical situation from which you want to find the coefficient. Then, write an expression for it using the expressions you found in part (b).

g) Perform your experiment, collect the data, and calculate the value for the coefficient of static friction.

h) Compare your result with values you can find in the literature. Does your result look reasonable?

The checkpoint is included after part (c) to ensure that the students are not going off in a wrong direction with their idea. The explicit instructions in parts (d)-(g) are given to train best practices for problem solving, which the students are expected to follow in the exams, but without the explicit instructions.

### 3.3 Assessment of Student Work

The main constraint on the types of assessment chosen as well as the percentage they contribute to the final grade is the consistency with previous and future offerings of this course. Fortunately, due to a long tradition of using innovative teaching strategies in Physics at SFU, previous exams already included conceptual questions as well as problems addressing different representations of phenomena, and of course questions testing a variety of problem solving skills. Therefore, it was at that time possible to design the various components of assessment with close alignment: For example, clicker questions from class or homework questions from Mastering Physics would show up on the exams in a modified form (sometimes just with a different „story line“), the tutorials would include the continuation of a problem started in class (for example, going from one to two dimensions), or a problem from the tutorials would be continued or expanded on the exam or in class (such as asking for the optimum angle for the ski jump).

# 4 Observations and Outlook

## 4.1 Students and TAs: Feedback and Challenges

As expected, many students were initially resistant to a change in the teaching method of the tutorials, particularly a more inquiry-based, active learning method, and very uncomfortable with problems that don't have a single, clearly defined correct answer. Over time, many became more comfortable with this way of learning science, maybe because the more experienced ones noticed that this is much more similar to how science is actually done, and certainly when they found tutorial-related questions on their exams.

The results for the midterms and the final exam were in the typical range for this type of course. For comparison and for internal quality assurance, we administered the FCI (Force Concept Inventory) to this as well as other first year courses.

The most noticeable effect was visible on the exams, where many students wrote their answers using full sentences and sketches (even when not prompted to do so) than what is usually seen in a first year service course. One of the TAs commented, „I did not expect that these students [not physics majors] would actually be able to solve this type of problems [conceptual]".

The TAs reported that some of the student groups were having fun with their activities, but for many, the one hour time slot proved to be too short, especially when they did not focus enough. For the larger tutorial sessions (up to 24 students), it was very challenging for the TA to provide adequate feedback. These issues will need to be addressed with a different way of scheduling in the future. An issue that TA training cannot solve is the difference in language skills among the TAs (in many departments, the majority of physics graduate students does not speak English as their first language). This issue can be addressed by specifically assigning qualified TAs to a course like this that requires them to interact with students much more than in a traditional tutorial or lab.

## 4.2 Anticipated Long-Term Benefits for the Department

The tutorial worksheets designed for this course will be shared with other instructors, with the intention to further improve them and to create a larger collection of worksheets in the future, so that instructors can pick and choose. Similary, the clicker questions and exam questions will be collected and made available, in a systematic way, to anybody teaching this course, along with existing question pools created by other instructors.

The teaching intervention for this course, the tutorials, has renewed a long standing interest in the department in data collection with concept tests, which is expected to continue over the next years. It is also expected to inspire future PER projects investigating the efficacy of teaching interventions like this: For example, the inclusion of epistemological issues and the hints towards calculus worked very well for a small group of students, but was clearly beyond what the majority of students were willing to digest. It is highly desirable to find out what made it work for the small group, in order to make these topics more accessible for a larger number of students.

Beyond the practical implications, there is an effect on the teaching culture within the department and beyond: TAs often a very conservative approach to teaching, but the tutorials gave them the opportunity to experience more student-centered learning first hand. This benefits the interest in teaching and teaching innovations that is already growing among graduate students. It even motivated one of them to consider a career in Physics Education Research.

The opportunity was also taken to showcase the tutorials during the annual Symposium on Teaching and Learning at SFU, in May 2013. Instructors from other departments were invited to experience the tutorials that we offer to their students, acting as „students“ themselves, with one of my TAs and myself acting as TAs. Enthusiastic feedback was received, with comments such as „who would have thought that learning physics can actually be fun!“

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