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A “Flipped” Approach To Large-Scale First-Year Physics Labs

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ABSTRACT

We describe a new approach to our first-year lab that has an eight-week formative learning part followed by a summative application in a four-week project. A key feature is that students perform some experiments at home and bring the data to class for discussion and analysis. Performance on our diagnostic test shows that students are generally learning the specific scientific skills that are targeted in our labs.

INTRODUCTION

The Physics 100 course at UBC is an algebra-based course for students that did not take physics in grade 12. The enrolment is typically 750 students in three lecture sections and 17 laboratory/tutorial sections; most of the students are interested in the life-sciences. The lab component used to be a fairly typical ‘cookbook’-type lab in a bi-weekly three-hour format (alternating with the problem-solving tutorial) with a focus on enhancing conceptual understanding and on acquiring technical lab skills. In 2010 we decided to transform our labs. In part we wanted to have weekly labs and tutorials (both are now weekly 1.5 hour-long sessions) to obtain better synchronization with lecture, but the main reason was that the labs simply did not work. We observed that students often had difficulty relating their data to the theory that was clearly presented in the lab manual. Furthermore, students did not acquire a solid understanding of uncertainties, and failed to grasp the general nature of the scientific tools and methods that were the focus of the lab. This is not an uncommon situation in first-year physics labs [1,2,3].

An analysis of the cognitive tasks in such a standard lab shows why it is ineffective: students must figure out how to take data with unfamiliar equipment, read lengthy instructions, decide when data are good enough, plot and analyze data, manipulate data so that questions can be answered, and perform an error analysis – all in a relatively short amount of time. Typical lab experiments are therefore designed to yield 'clean' data that allow the students to get a specific 'correct' answer, such as the value of a physical constant. Specialized equipment (carts on tracks, inclined planes) makes the labs somewhat artificial, thus students do not perceive these methodologies as analytical tools that can help them make sense of the physical world.

THE NEW LAB DESIGN

Our new lab design focuses on *doing authentic science in the real world*. Students gain experience and confidence with conducting scientific investigations to answer questions while the outcome of an experiment is not known a priori. The overall goal of the lab is for students to be able to design and carry out an experiment, analyze the given data, determine uncertainties, and present their findings to their peers. In the first eight weeks of the term, we build up a "scientific toolbox" using inquiry activities and experiments with a focus on understanding experimental data and uncertainty. The first lab assumes very little prior knowledge and subsequent labs build on the preceding labs thus slowly building up students' skills from week to week. This idea of having students practice their increasingly complex lab skills over many weeks is not new [1,2], but in our implementation, lab homework (~ 30 minutes) connects consecutive lab sessions: students are asked to perform relatively simple experiments at home and bring their data to the next lab session, or they are asked to perform further data analysis at home which is then discussed in the next session. The homework thus ties the labs together in a cyclic process (lab -> home -> lab). This makes classroom time available for discussions on planning ("how many data points should I take?"), data analysis, and other challenging concepts ("what are the sources of uncertainty in my experiment?") that require peer and TA support, similarly to the 'flipped classroom' that increasingly replaces traditional lectures. While all experiments are performed in pairs, interaction between pairs is encouraged (and often facilitated) to promote peer feedback. The studio-physics style layout of the lab room with six students per table supports this format well. Whole-class discussions triggered by clicker questions take place at the beginning and end of each lab.

Most experiments in class rely on familiar equipment such as rulers and stopwatches. At home, students choose their own equipment (from what is typically available), such as string and set of keys to build a simple pendulum. The choice of equipment is given to students as part of the experimental design and is not dictated by the lab manual. We deliberately avoid complicated equipment and complex procedures and there is no explicit attempt to enhance understanding of physics concepts – the focus is on understanding the concepts of measurement, similar to the lab design reported by Redish and Hammer [2].

We believe that doing experiments at home may help relating physics to everyday life and so the last four weeks of the lab are dedicated to a final project to answer a question of their choice. Students perform an experiment at home (in pairs) with everyday equipment, analyze their data with the tools they have learned in class, and present their results to instructors and peers in form of a poster. There are two sessions to support the students in their final project before the poster session. In the first support session, proposals are discussed in terms of feasibility and appropriateness and in the second session, preliminary data is looked at and suggestions are made by peers and teaching assistants. The final project also serves as the main assessment of the lab. During the first eight weeks, students are assessed only on effort. In-class participation (clickers, worksheets) and lab homework are characterized very broadly as sufficient, borderline, or insufficient, using rubrics. We found that this assessment strategy works well; the students seem to understand that their engagement in the first half of the term is essential for success in their project.

ARE STUDENTS LEARNING?

As mentioned above, the final lab project serves as the main assessment of the labs. Since the project is done in pairs and at home with sufficient time, one would expect a relatively high average mark. The average project marks in 2011, 2012, and 2013 are 86%, 88%, 90%, indicating that students are performing as expected. Most students are able to decide how much data to take, how to analyze and present their data, and how to come up with reasonable error estimates.

To assess student learning more directly, we developed a data skills diagnostic test (available from the authors upon request) that tests the students on the specific scientific skills that are targeted in our lab. The test focuses on interpreting histograms, graphs, and standard deviation, drawing reasonable conclusions from given data, choosing appropriate data samples, evaluating agreement and quality of data. The test was first developed in 2010 along with the new lab. Unfortunately, we do not have a baseline on the diagnostic before the lab revision took place. Furthermore, the diagnostic test itself underwent changes since then. In 2012, students' scores on this test improved from 0.69 (SD = 0.25) to 0.82 (SD = 0.21) during the first eight weeks of the course (Fall 2012), corresponding to gains of 42% (that is, students' improvement was 42% of the maximum possible improvement). This improvement is highly significant: $t(516) = 11.5$, $p < 0.0005$. The high pre-test scores are somewhat problematic as this decreases the sensitivity of the test to student learning. The learning gains as measured by the test thus have a relatively small dynamic range. We note that developing a good lab diagnostic test is challenging, as experimental design and data analysis are contextualized within research questions, apparatus, etc. The decontextual nature of the test requires transfer of abstract understandings of these skills (e.g., the choice of appropriate graphs).

We also look at motivation and students' attitudes towards the new labs. Students were contacted by e-mail 4 months after the end of the course in 2012 and were invited to fill out a voluntary online survey about the Physics 100 course and its components. Of the 158 respondents 75% said that the labs have helped them to achieve the following goal: "learn to design and analyze experiments", and 55% said that the project helped them achieve this goal. A quarter of the students (27%) agreed that the skills and knowledge targeted in the lab will be useful in other courses and 20% said the same about the project. Some students commented that they did not like the focus on data skills and wanted more 'typical' physics experiments. Students also commented that the labs did not help them 'learn physics'. We certainly need to find out more about our students' attitudes to help us convince more of them why data and graphing skills are so important.

SUMMARY AND FUTURE WORK

We have designed and implemented labs in which students do a significant portion of the experimentation at home. In our 'flipped' approach, classroom time is spent on peer discussions and making sense of important concepts related to data analysis, uncertainty, and representation in graphs and histograms. We believe that our new inquiry-based labs are a significant improvement over the previous, more traditional labs that were not successful in teaching data skills. We have some evidence that students generally acquire the skills we want them to learn, but our lab diagnostic test needs further improvements to increase its sensitivity to student learning. Furthermore, the overall appreciation for our first-year labs still needs to be improved and we will conduct surveys and interviews to find out more about students' views. This will help us make further improvements and convince more students of the value of the concepts and skills targeted in our new labs.

All lab worksheets and more details are available at http://www.phas.ubc.ca/teaching-support.

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