Final Report on Physics-WID Project – January 2019

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A. Introduction

Physics labs in Dawson have traditionally been closely linked to the content seen in class, and, more often than not, formulated in a follow-the-recipe approach where students aiming at producing experimental data to verify well-known laws. This approach may not be effective in stimulating engagement or a reflective practice of the scientific method. This observation was the starting point for our original WID project proposal.

Recent studies, including one from Holmes and Wieman (Physics Today **71**, 1, 38 (2018)) have shown that students understanding of the material presented in a course is not increased by revisiting the pertinent concepts in a traditional lab activity.

Our two focus group interviews, conducted with six former students, showed that very few ideas seen in the lab stayed in a student's mind with the passage of time.. They could remember fancy demonstrations, but they failed toremember how to correctly interpret them. The few meaningful moments that were retained often had to do with occasions where the students were at the center of the action, either by being encouraged to be more autonomous scientists, or from *eureka* moments they had on their own.

As a last straw on the camel back, a few former students now in physics-related programs in university briefed us on the huge differences in data analysis between cégep and university. In short, what we teach is a simplified and artificial version of the conventions that are used in a real scientific community. Our labs are far from being an authentic research experience.

These observations indicated to us that we needed to review and renew our approach to lab design. After some intellectual seeking and wandering, a lot of reflection, and many discussions with colleagues, we developed and refined a list of skills that we wanted students to develop in the lab and identified several design principles that could guide the development of new labs.

B. Design Principles for Authentic Physics Laboratory Activities

I) Identify science practices that lab activities aim to develop

During the fall 2018 semester, a group of faculty met to discuss labs and formulated general principles for their design. We concluded that to be meaningful to students, labs should be:

- Authentic, focusing on developing skills that will be relevant to future work in science;
- Engaging, by being student-centered and by leaving more room for the students to be involved in the design of the experiments;
- Memorable, in the sense that the knowledge acquired will be long lasting.

To produce these meaningful labs, we wish to focus on four areas of lab work by providing opportunities to students to practice skills in the attainment of nine specific learning outcomes:

1. Autonomy of students learners:
    - Formulate hypotheses, design experimental protocols, and iterate to improve protocols.
2. Critical thinking:
    - Analyze data to confirm or refute hypotheses.
    - Question, challenge and modify scientific models used to explain data.
3. Uncertainty analysis:
    - Understand the probabilistic nature of uncertainties.
    - Identify, estimate and calculate uncertainties.
    - Compare results using uncertainty analysis.
4. Scientific writing skills:
    - Produce clear and well-presented tables and graphs.
    - Formulate arguments based on experimental data.
    - Write lab reports according to the usual conventions.

II) Flip out instruction for lab procedures, background knowledge

In order to give more time on task for students in the labs, a portion of the theory has been offset in pre-lab exercises combined with on-line explanatory videos of the new material introduced. Students then come to the lab better prepared which should help in making their work more meaningful.

Nadim created multiple videos to this effect. Some of the clips are targeting uncertainty analysis and can be used in multiple courses, while others are specific to individual lab topics.

Some of the labs created are not related to the content of the course and their objective is to introduce and practice lab skills such as uncertainty analysis and scientific writing.

III) Design authentic experimental contexts for lab activity

The reformulated labs each try to address specific objectives. Many are requiring students to write experimental protocols, often prior to the lab. In doing so, students are forced to reflect on the goal of the lab and on how it can be attained. For instance, in asking students to show that acceleration is proportional to force while using the hanging mass and cart system, students have to realize that, in their protocol, they must keep mass constant.

A few of the NYA labs are used to introduce uncertainty analysis, including both systematic and statistical contribution. To be assimilated, these skills must be used multiple times. It will be important to develop a sequence of labs for the courses that get students to reuse and build on prior knowledge.

Finally some labs aim at getting students to question results. From discrepancies between the results and the theoretical model, they need to either improve their experimental protocol or modify the theoretical model. An example of this would be to realize that for the hanging spring, the stretch for a hanging mass of zero will not be null in contradiction with a simplistic application of Hooke's law. Students are then lead to realize that the mass of the spring itself will have an effect on the model by shifting the y-intercept.

IV) Design authentic writing/reporting activities

Materials have also been developed to promote good scientific reporting. That includes writing, but also creating proper tables and graphs, and encouraging the use of traditional lab journals.

During the Fall 2018 semester, all NYA teachers agreed to have one formal report for which students would get some feedback and would be allowed to resubmit. This practice could be extended to the other courses.

C. Conclusion & recommendations

Although a lot of work has been done, it feels like we are just starting! In our first progress report of June 2017, we were encouraged by our progress and our preliminary results:

> "As March turned into April, the development and testing of prototype versions of new labs began, with a heightened emphasis in two areas: provoking critical thinking about assumptions related to theoretical models, and raising awareness of measurement uncertainties. Nadim prepared new labs for Astrophysics and for Waves and Optics. For the latter, new introductory PowerPoints and videos were developed with the goal of ensuring that students came to the lab well prepared, with a clear understanding of objectives, equipment, and procedures. Additionally, to emphasize authentic scientific practices in the communication of results, a revised reporting format was developed that asked students to pay more attention to narrative continuity. They were also prompted to evaluate more critically the validity of their results, and to posit future refinements in measurements or changes in procedure – in other words, the kinds of suggestions they might make if they were reporting to the director of a research laboratory.
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> Subsequent student focus group interviews suggested a higher level of engagement and learning in the revised labs. A majority of students agreed that the revised lab activities created opportunities to think and act in the manner of real scientists. Accordingly, "The project will continue its life in the fall with the modification of additional lab activities in Mechanics and Waves and Optics," says Nadim. "In all cases, the goal will be to encourage students to foster their critical thinking skills and their abilities to assess and improve their lab results."

Now, two years later, we are still encouraged by the impact of these changes. We see three directions for new efforts in the near future:

1. *Elaborate a progression of the teaching of the lab skills from course to course in Physics.*

   The department needs to agree on a progression chart detailing the skills that will be covered and the level of proficiency expected for each course of the program. Each course should build on the skills and content developed in the previous courses. By the time they graduate, students should have covered and practiced sufficiently all the lab skills we believe to be important.

2. *Develop teaching materials that align with our lab learning objectives.*

More material is needed in order to cover all the objectives we deem important. In particular, models of lab reports could be very useful in setting expectations to both students and teachers.

3. *Agree on common evaluation methods for lab skills.*

The most powerful method we had in the last few semester to agree on lab-related topics to be covered was to include questions on lab skills in the final exams (for instance propagation of uncertainty in NYA). Agreeing on other topics to cover in common evaluations could promote key lab skills across all sections of a course.

D. Useful resources

- Developing quantitative critical thinking in the introductory physics lab, N.G. Holmes, 2015 PERC Proceedings.
  - Introduces an approach based on iterations that promotes critical thinking in the lab by scaffolding decisions with some quantitative comparison tools.
  - Explicitly showing some examples of labs.
  - Further study on the same topic can be found in: Teaching critical thinking, N.G. Holmes, C. Wieman, and D.A. Bonn, PNAS, September 8, 2015, vol. 112, no. 36,p. 11199–11204
- Framework for Incorporating Model-Based Inquiry into Physics Laboratory Courses, B.M. Zwickl, N. Finkelstein, and H. J. Lewandowski, 2013.
  - Other approach to iterative labs and critical thinking in the lab.
- Measuring the impact of introductory physics labs on learning and critical thinking, C. Wieman and N.G. Holmes, 2015 PERC Proceedings.
  - Questions the idea that the labs reinforce the learning of the concepts shown in lectures.
- Inquiry-Based Writing in the Laboratory Course, C. Moskovitz and D. Kellogg, SCIENCE, VOL 332, 20 MAY 2011.
  - Presents a different perspective on student writing in science. In particular, the idea of the double-blind report described on page 920 in very interesting.

E. Project Workflow

- Jan 2017: Interviews with 6 students on their perception of the labs done in mechanics (3 former students of JF) and E&M (3 former students of Nadim)
- Jan-Feb 2017: literature review on: lab approaches; teaching of data analysis; and scientific writing.
- March-April 2017: first attempts at making more authentic labs in Astrophysics and Waves.
- March April 2017: student interviews to obtain feedback on the new labs.
- March 2017: presentation to a subset of teachers from the department.
- Fall 2017: multiple attempts at new labs with more or less success in NYA and NYC.
- Winter 2018: refinement of many labs.
- Fall 2018: Set of 5 NYA and 3 NYC tested labs.
- Fall 2018: 3 meetings focusing on labs with members of the NYA course committee that helped refined desired outcomes of the labs.

F. List of new materials

A. NYA set of labs focusing on introduction to uncertainty analysis:
   1. Measuring bingo chips:
      - Intro to distribution functions.
   2. Measuring the acceleration due to gravity:
      - Evaluating standard deviation and statistical uncertainty.
      - Combining statistical and systematic uncertainty.
      - Revising experimental methods to reduce uncertainties.
   3. Effect of surface area on coefficient of friction:
      - Writing a hypothesis and design an experimental protocol to test it.
      - Propagating uncertainties for functions of one variable.
      - Comparison of data sets with uncertainties.
      - Writing a conclusion based on data.
   4. Relation between force and acceleration:
      - Writing a protocol.
      - Revising a theoretical model.
   5. Ballistic pendulum:
      - Propagating uncertainties for functions of many variables.
      - Comparison of data sets with uncertainties.

B. NYC set of labs reinforcing ideas introduced in NYA:
   1. Measuring the spring constant:
      - Revising a theoretical model.
      - Comparison of data sets with uncertainties.
   2. Diffraction
      - Writing an experimental protocol.
   3. Spectrograph
      - Calibrating an instrument.
      - Writing an experimental protocol.

C. Reporting & write-up skills
   - How to correctly format a table.
   - How to correctly format a graph.

D. Preparatory powerpoints and Youtube Videos developed for the project.