Implementing Investigative Labs and Writing Intensive Reports in Large University Physics Courses

Kathleen Foote, Physics Department, University of British Columbia, Vancouver, Canada; kfoote@phas.ubc.ca
Silvia Martino, Honors Physics Graduate, University of Auckland, Auckland, New Zealand; silvia.martino.nz@gmail.com

Undergraduate physics programs are increasingly facing pressure from university and college administration, industry, and funding agencies to improve training of our undergraduates. Increasingly, tertiary institutions have redefined their graduate profiles and mission statements encompass more than just content knowledge, including skills that will help students succeed in today's fast-paced world. Many physics departments have started to incorporate the results of physics education research and cognitive science, by adopting more active pedagogies.[1-2] Student Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP)[3] is one such educational innovation that has spread widely around the United States and abroad. SCALE-UP integrates the lab, "lecture" and tutorial sections of the course in a reformed classroom to allow large enrollment university courses to benefit from interactive instruction. This article explains how the University of Auckland developed more open-ended, resourceful lab activities to be completed by large classes (~125 students) that enhance understanding of physics while developing transferable writing-related and critical thinking skills.

Writing helps students solidify their understanding of course content and simultaneously promotes aspects of critical thinking such as conceptualization, application, evaluation, and synthesis. Writing encourages students to synthesize material from their textbook, class discussions, and labs while comparing theory to practice.[4] Peer review has been shown to improve student writing, their confidence in interpreting information, and understanding of complex processes.[5-6]

Studio Physics at the University of Auckland

The University of Auckland recently adopted a Studio Physics format for their calculus-based Advancing Physics 1 and 2 courses, highly influenced by the SCALE-UP model. We renovated the first year laboratory to have round tables that sit three groups of three students per table (maximum of 125 students), whiteboards on the walls, and LCD monitors around the perimeter of the classroom *(see Figure 1)*. The first semester course has an enrollment of around 300 students, including those who want to major in physics.

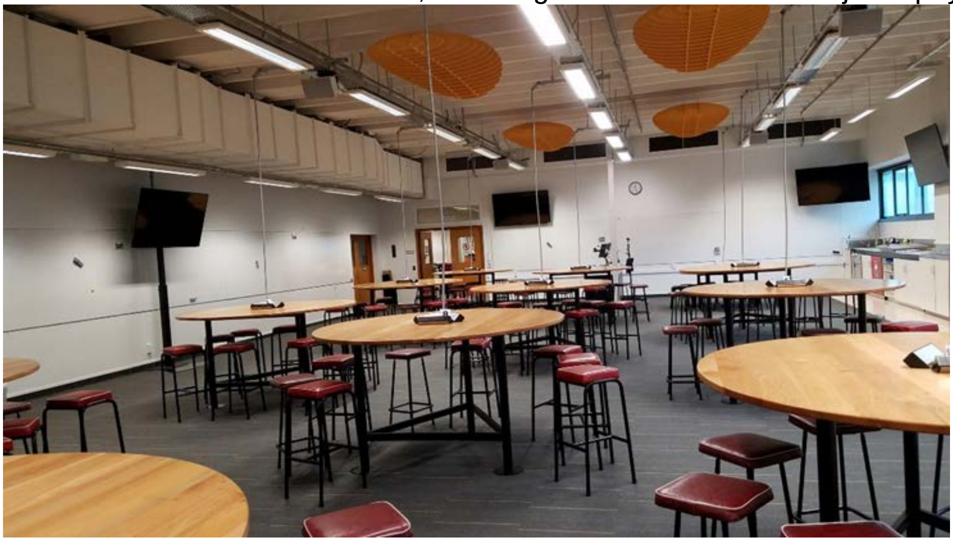

Figure 1: Studio Physics classroom at the University of Auckland

The Experiments

After renovating the first year laboratory classroom, the next challenge was to redesign the first year laboratory curriculum, which previously consisted of three-hour traditional experiments with detailed instructions. We planned to move to more open-ended investigations where students have autonomy in data collection, with enough guidance to finish in the two-hour sessions. We aimed to use inexpensive and easy-to-store equipment, use technology and create inquiry-driven activities.

One of the main tools we utilized was Lablet[7], an Android application for tablets developed by the University of Auckland Physics department so students can use a versatile, familiar tool to do science. Lablet allows students to collect and analyze data (often with video analysis), view graphs, perform calculations, and answer questions on a tablet. This facilitates a paperless workflow and removes the need for expensive, single-purpose lab equipment.

We planned to scaffold the lab activities (described in Figure 2) so the labs became increasingly open-ended. All of the labs were presented as the one sentence challenge shown below, without any formal written instructions, although Lablet sometimes allowed students to “infer” a procedure. Before students attempted the formal labs outlined below, we familiarized them with the Lablet apparatus through a ‘describing motion’ activity. In this exercise, students filmed a thrown projectile, used tagging to track the trajectory and interpreted the generated graphs. Since the first two labs involved falling objects, this structured introduction to Lablet helped ensure everyone had the requisite familiarity with the data collection tool.

Topic	**Challenge**	**Apparatus***	**Bonus features**
Newton’s Laws, Drag Force	Is drag force of a falling muffin wrapper proportional to a) velocity, or b) velocity squared?	Muffin wrappers/ basket coffee filters	Introduction to graphical analysis and linear regression
Conservation of Energy, Kinematics	Determine the spring constant of a ballistic launcher.	Ballistic launcher	After submitting their reports, students were encouraged to read an article [8] that introduces effective mass to account for missing energy.
Travelling Waves	Determine wave speed in a slinky.	Slinky	Use and comparison of multiple methods
Calorimetry, Properties of Metals (density)	Determine the identity of mystery metals using calorimetry.	Mystery metals, calorimetry apparatus (electric kettle, insulated cups, thermometer)	Interdisciplinary focus (chemistry)

Figure 2: Table of Labs. *Apparatus includes required equipment beyond the Lablet, meter stick, and stopwatch.

The Report Format

Since we wanted students to improve their scientific writing, we switched the report format to short, argument-based reports. Previously, reports were highly structured, to the point of being formulaic, with little scope for originality or critical thinking; lengthy sections were often devoted to repeating portions of the lab manual, despite students being instructed not to do so. The abbreviated report forces students to eliminate extraneous, repetitive, uninteresting sections of the full report, which can be taxing for students to write and tutors to grade. Instead of traditional labs with a “right answer”[9], we wanted students to defend their methods for collecting, analyzing, and interpreting data, and using models and mathematics, and to improve their abilities to construct explanations, argue from evidence, and communicate scientifically. Since the literature reveals many undergraduates focus on the technical aspects or “rules” of writing, such as formatting and section headings, rather than on communicating effectively,[10] we minimized formatting requirements but provided a detailed rubric for guidance. For instructors, the open-ended experiments made lab reports more interesting to read, and decreased time spent reading regurgitated parts of the lab manual, while the peer-review process helped increase the quality of the final submission.

The Rubric

We created a detailed rubric to provide meaningful feedback while simplifying grading, which has been shown to be one of the biggest challenges for integrating writing in science courses.[11,12] Specifically, “assessing any kind of written work, particularly in a discipline where there is little tradition of such activity, is a complex exercise. This is especially so where several graders are involved, since they may have differing views as to what constitutes the essential assessment criteria for a piece of writing”.[11] This study of reformed reports in university physics revealed graders often focused on surface-level features such as grammar, spelling and punctuation, and produced large variation in feedback. To minimize discrepancies of this sort, the rubric was developed (highly influenced by Argument Driven Inquiry[13]) with detailed criteria to assess reports objectively and provide actionable feedback, while minimizing the amount of writing required of the grader.

The rubric was also intended to guide students in preparing and self-evaluating their lab reports, using clear, descriptive language to express both the criteria for grading and the levels achieved. Criteria for grading were expressed as questions, such as “Did the author include high-quality evidence in the report?”, and levels of achievement as “Yes”, “Partially”, or “No”.[13] The literature claims this approach can help students more than traditional methods of assigning a numerical or letter grade based on standards which students perceive as opaque or arbitrary.[14]

Introducing The New Format to Students

When we first introduced these labs to students, we addressed common misconceptions about scientific writing, including “science is objective so scientific writing doesn’t involve creativity and/or argumentation”, “doing physics labs replicates real science - science advances in a stepwise manner to a ‘right’ conclusion”, and “as long as physicists are good at math, they don’t need to write well”. We discussed the role of argumentation in scientific writing, the writing activities scientists typically engage in (including peer review), and qualities of good scientific writing. Since we specified a one page limit for reports (plus one page for tables and figures), we spoke about the importance of concise communication, including the examples of “elevator pitches” when networking at conferences or job interviews and abstracts that often determine whether people continue to read a scientific paper or attend a scholarly talk.

Peer Review

We introduced peer review as a responsibility of practicing scientists. The review process also allowed students to see how someone else approached the experiment and report, to receive formative feedback on their report before the final submission, and to build skills such as critiquing and evaluating their peers' reports.

Initially, we had students grade each other using the rubric in class without explicitly requiring written comments. This often resulted in inflated marks, inspiring false confidence in the quality of reports, causing disappointment when instructors graded the assignments. Because this approach was not as productive as we hoped, we spent class time discussing how to provide specific, constructive feedback and gave students examples of productive versus unproductive comments. For the second review, carried out online, students evaluated each other's reports using the rubric and received points for identifying one strength and one area for improvement. Still, the quality of comments varied widely. For the third iteration, students evaluated their own reports using the rubric and answered six guiding questions about their peers' work that targeted shortcomings, such as "Did the author identify a sensible experimental aim that was addressed in the conclusion of their report?" This successfully helped avoid the false confidence issue, standardize and raise the quality of feedback.

Reflections

A paper questionnaire administered on the last day of class revealed that students liked the labs and wanted more. They commented, "these labs force us to think rather than following a set of instructions". Another student wrote, "the labs are something I like and don't like. I feel more like a scientist when doing the lab but also let me know how hard it's to find a correct way to do it. It needs a lot of effort, maybe we could have a longer time, proper procedure". This reveals that some students still want a "right" procedure, but having students struggle with ambiguity gives them a more authentic experience of the scientific process.

The report format resulted in the production of diverse reports, where plagiarism was nearly non-existent and the rare case of students working together too closely could be immediately identified. The quality of reports increased dramatically over the course of the semester, with evidence of both an increase in scientific critical thinking (for example, listing sources of error that were relevant to the specific experiment and describing how they would skew results) and improved ability to eliminate unnecessary information and construct a strong argument concisely. When students were asked what skills they developed during the semester, "writing lab reports" was a top response.

In practice, with the help of the rubric, reports took about 5 minutes to grade, which for sections of 100 students adds up. Because we value communication as a key learning outcome, we justified the expense of TA graders. If resources are scarce, instructors of large classes could develop a grading scheme where students receive points for submitting reports and participating in peer review, but the instructor only grades one final report (chosen at random) in detail.

We did not use the grades students assigned each other for any purpose, but if we were to do this in the future, we would need to spend time calibrating the peer review process. Software and tools exist that scaffolds peer feedback through asking students to choose the "best" answer of various pairings, either overall or for specific criteria.[15] This could further improve student's ability to review each other's work, which is far less trivial skill than initially assumed.

One of the most interesting observations from these labs was how students could confidently "complete" the experiment, but occasionally the reports revealed a severe lack of conceptual understanding. This was most clear during the first lab activity, on terminal velocity, where Lablet prompted them to drop an increasing number of muffin wrappers. Students took videos, checked in with a teaching assistant to use the graphs to calculate terminal velocity, and we naively assumed they understood the experiment. When students turned in reports, almost one third used the drag force equation in their textbook to calculate drag (instead of realizing that weight equals drag force at equilibrium) then proudly reported a perfect linear relation with mass (which is in the numerator of the drag force equation). We discussed this phenomenon, reminding the class that going through the motions of an experiment, as they might have in the past, does not work when activities are open-ended. In subsequent experiments, this was less of an issue, potentially because the other experiments were not as conceptually subtle, Lablet did not provide as much structure, and/or this was an effective reminder.

In Conclusion

Overall, the reformed structure of experiments and reports proved that meaningful labs can be resourcefully implemented in large classes. The more open-ended nature of the experiments and reports made the activities more fun for the students to complete and instructors to read, while helping students build transferable skills that can be carried into their future courses and careers.

Acknowledgements

This project was funded by University of Auckland's "Writing Writing Everywhere" Initiative and author Silvia Martino did much of the detailed development of these laboratory exercises. Thanks to Alistair Kwan from CLeaR for inspiring the project and Anna Yang for her contributions.

References:

1. Vision and Change: A Call to Action, American Association for the Advancement of Science, Washington, DC, (2009).
2. R.R. Hake, "Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses," Am. J. Phys. 66, 64–74 (Jan. 1998).
3. R. Beichner, "The SCALE-UP Project: A Student-Centered, Active Learning Environment for Undergraduate Programs," an invited white paper for the National Academy of Sciences, (September 2008).
4. R. E. Beiersdorfer and J. Haynes, "An integrated approach to geologic writing for non-science majors based on study of a California river". *J. of Geological Ed.*, *39*(3), 196-198 (1991).
5. W. H, Guilford, "Teaching peer review and the process of scientific writing". *Advances in Physiology Ed.*, *25*(3), 167-175 (2001).
6. K. Brieger and P. Bromley. "A model for facilitating peer review in the STEM disciplines: A case study of peer review workshops supporting student writing in introductory biology courses." *Double Helix* 2 (2014).
7. https://lablet.auckland.ac.nz/
8. A.B. Western, "Dramatic Demonstration of Energy Conservation Using Projectile Motion", Accessed: https://www.rose-hulman.edu/~western/slingsho.html
9. P.M. Kind, V. Kind, A. Hofstein, and J. Wilson. "Peer Argumentation in the School Science Laboratory—Exploring effects of task features." *Inter. J. of Sci. Ed.* 33(18), 2527-2558 (2011).
10. J. M. Gladstein. "Conducting research in the gray space: How writing associates negotiate between WAC and WID in an introductory biology course." *Across the Disciplines* 5. Rewriting Across The Curriculum, Special Issue (2008)
11. S. Allie, A. Buffler, L. Kaunda and M. Inglis, "Writing-intensive physics laboratory reports: Tasks and assessment". *The Phys. Teach.*, *35*(7),399-405 (1997) .
12. A. Kwan. Constructive alignment for deep learning: very short, argument-based laboratory reports. *Inter. J. of Innovation in Sci. and Math. Ed.*, *23*(2) (2015).

13. The rubric was adapted from the Argument Driven Inquiry (ADI) Investigative Report Peer Review Guide - Undergraduate Version: http://www.argumentdriveninquiry.com/instructional-materials.html.
14. E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren. "Scientific abilities and their assessment". Phys. Rev. ST Phys. Educ. Res. 2(2), 020103.1-15 (2006).
15. T. Potter, L. Englund, J. Charbonneau, M.T. MacLean, J. Newell, J. and I. Roll. ComPAIR: A New Online Tool Using Adaptive Comparative Judgment to Support Learning with Peer Feedback. Teaching & Learning Inquiry, 5(2), 89-113 (2017).

Biography:

Kathleen (Katie) Foote was a Professional Teaching Fellow in physics at the University of Auckland in New Zealand but now works at the University of British Columbia. She holds a PhD in physics from North Carolina State University where her PhD advisor, Dr. Robert Beichner developed a popular form of Studio Physic (SCALE-UP). Her research, and passion, involves bringing reformed teaching into university classrooms in a sustainable manner.

Silvia Martino recently completed a postgraduate Honors degree in physics, with a dissertation on data visualization in virtual reality, at the University of Auckland in New Zealand. After many years of tutoring and working as a teaching assistant in undergraduate laboratories, she is eager to see how developments in physics education affect future generations of students.