Introductory Physics Labs: A Tale of Two Transformations

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I. INTRODUCTION

There are many challenges that physics faculty face when teaching introductory labs. One of these challenges is engaging students in authentic science practices. Another has been highlighted given the current global pandemic—specifically how to engage students in our laboratory courses while maintaining appropriate social distancing and hygiene standards. We have chosen to answer these challenges by transforming our labs. . . twice. We discuss the rationale behind the first transformation to a practice-focused curriculum. When March 2020 rolled around we needed to transform our labs again, this time to accommodate online learning. This paper discusses two chief questions: "What are we doing to engage students in science practices?" and "How did we make all of this work online?"

The physics labs at our institution in Fall 2016 very much mirrored the national narrative. The lab curriculum had been largely unchanged for about 20 years. Moreover, the equipment commonly used by students was outdated—triple beam balances and hand-drawn graphs were standard. In the same year, as part of an interdisciplinary team interested in engaging students in scientific practices as well as assessing those scientific practices, we secured funding, both internally and from the NSF, to change this status quo in physics, biology, and chemistry. All three departments transformed their labs using a pedagogical framework entitled, Argument Driven Inquiry (ADI),[4–6] which has been specifically designed to engage students in authentic science practices. In physics, we also utilized the AAPT Lab Recommendations to guide our transformation.[7]

We were satisfied with our progress when March 2020 rolled around, and with it, the mandatory shut-down due to the global COVID-19 pandemic. With students off campus, we had to abruptly shift our delivery to an online format and quickly realized that some of the activities that we utilized in the face-to-face sections had to be adapted to online use. Going forward, we have further adapted what we are doing so that students can still participate in a hands-on laboratory experience in an online laboratory course.

II. INSTRUCTIONAL CONTEXT

Regional State University is a public doctoral granting university in a rural, economically depressed part of our state. The university mission is focused on regional transformation and service to this region. The total combined student population in Fall 2019 was 28,651 largely comprised of undergraduates (23,081). Our physics labs (Physics I lab and Physics II lab) are each 1 credit courses that meet for 2 hours per week. These courses serve both of our Calculus-based and Algebra-based physics lecture courses. Most ($\sim$ 75%) of the students who take our lab course are in (or have taken) the corresponding Algebra-based physics lecture course. These labs also fulfill the general education requirement for science lab courses at our university.

Labs are supervised by Author 2, but each section is run by Graduate GTAs (GTAs). The transformed curriculum was jointly written by both of the authors. GTA training was also greatly enhanced when the new lab curriculum was put in place. Both authors, along with colleagues in Biology and Chemistry, run a training for all GTAs in Biology, Chemistry, Geology, and Physics as these disciplines are all using the same curricular format for their labs. Author 2 runs a weekly prep meeting with the GTAs, and Author 1 and the research team have supervised various aspects of the transformation especially important for research such as curricular implementation[8] and assessment grading practices[9].

III. TRANSFORMATION #1: ARGUMENT DRIVEN INQUIRY

Argument Driven Inquiry (ADI) is a pedagogical method that was developed to make science labs in school better match what actually transpires in authentic research settings[4–6]. In traditional labs, we often ask students to answer questions, or measure quantities, that are well-known using procedures that have been refined over time. In ADI labs, we give students a guiding question to answer experimentally (e.g., "Does the force a fan exerts on a cart depend on the mass of the cart?"). This allows students to design a procedure for an experiment that will answer that question, collect and analyze their data, and make claims based on their data. We accomplish this by having students engage in a three-part cycle:

- Pre-Lab - Introducing the context
- Proposal Development and Data Collection
- Argumentation and Peer Review

In the sections below, we will comment on each part of the cycle, focusing on both students and GTAs. Each lab course completes at least three cycles (usually four in the Fall and Spring), and the semester ends with a practical exam where students engage in this process on a shortened cycle without peer feedback.[9] We have provided supplemental materials with more details about each of the labs in our curriculum.

A. Session 1: Pre-Lab

Part of the goal of any laboratory is to help students develop a familiarity with certain tools and equipment common to the lab. The purpose of the pre-lab reading and activity is to give students familiarity with the equipment they will be using. For the investigation described previously, "Does the force a fan exerts on a cart depend on the mass of the cart?" we need students to become familiar with a few things, such as what we mean by a cart, and give them some tools that they need to be able to answer this question. As a part of the pre-lab reading, students are given information about linear regression—both how to run it in Excel, and how to interpret the output, and how we can estimate instantaneous velocity given position vs. time data. For this experiment, we give them a cart (leaving the fan off for now) and have them measure the acceleration of that cart down a ramp using an ultrasonic motion detector to collect position vs. time data for this motion. Students work in pairs and turn in a brief summary of this work on the course management system. For this investigation, it is the first time that they create graphs, so we set norms for graphing such as helping them decide which variable to put on the x-axis and the y-axis as well as including units. Pre-lab assignments are designed to be graded in less than 1 minute/paper based on a rubric we provide to both students and GTAs.

B. Session 2: Proposal Development and Data Collection

During this session, students work in groups of 3-4 on the guiding question. They develop a proposal, get it approved by a GTA, and then collect and analyze their data. We have a format for proposal development that asks students to link the scientific concept being studied—in this example case, Newton's Second Law—to the data that they will collect. Students also need to propose a plan for analyzing their data and minimizing potential sources of error (such as friction). Once students have an approved proposal, they begin collecting and analyzing their data. This may lead them to refine or revise their method (which they are encouraged to do). Grading for the GTAs this week is minimal (students get full credit for getting their proposal approved). However, this is the most critical week for GTA training. GTAs have to be clear that the goal is to allow a diverse number of ways of collecting/analyzing this data. This can be uncomfortable for the GTAs and students alike. Students want "the answer," and GTAs want to provide one to them. However, experimental methods certainly have an impact on experimental results. One of the goals of this curriculum is to get students to understand this and apply it as they develop their experimental procedures and evaluate their results.

C. Session 3: Argumentation and Peer Review

During this session, the students begin by sharing their results. Students finish analyzing their data during the prior week, and prepare a "poster" on a whiteboard. One person from the group stays at the whiteboard while the other group members (travelers) go to other groups. The travelers learn what other groups did, and compare to their results in a structured argumentation setting. Groups spend about 3–5 minutes at a poster, and rotate so that they see at least 3 other posters. After the travelers return, critically, the groups spend time discussing what they saw and reflecting on their own results. What is exciting is that sometimes, these interactions actually drive groups to change their claims.[10]

Each student writes a shortened lab report consisting of three sections: an introduction to the scientific concept, a description of the experimental method or procedure, and a discussion section laying out their results and the evidence and justification supporting their results. The authors have created different peer review calibration videos for the students to watch so they can look for the same things that we are going to be grading them on when we get their final reports. Students complete their lab report and submit it by the end of the day. Then, students take part in double-confidential peer review that we facilitate online. They read and review two different lab reports using the same rubric as we do on their final drafts. Finally, they get their feedback and use this to revise their own lab report. At the end of this week, students turn in their revised, peer-reviewed final lab report. This is the heaviest week of GTA grading, each lab report generally takes about 3-5 minutes to grade.

IV. TRANSFORMATION #2: ONLINE ADAPTATION

A. Sudden Transition to Online Instruction–Spring 2020

In March 2020 the COVID-19 pandemic forced most universities, including ours, to move all their classes online. Our Physics I and II laboratories had completed two out of four full investigations and the pre-lab for the third investigation face-to-face. We were forced to find a way to engage students in an online format while preserving the nature of the ADI laboratory experience. In addition, we gave the laboratory practical exam online. We required student investigation groups to find a method for online collaboration in which everyone in the group could participate. Tools students used were the Course Management System communication tools (Canvas), WebEx (video interaction platform licensed by our university), and other online communication applications not managed by the university (e.g., group chats). We have detailed the adaptations we made to the curriculum in the supplementary materials. One of the principles that we used while making these adaptations is that students should exclusively use university-supported (Microsoft Office) or open source resources.

The pre-lab phase was managed one of two ways. As this is the most prescriptive part of the lab and intended to introduce students to data collection and analysis techniques, in-person activities were modified for online use by creating (or using) videos or simulated using *Glowscript*.[13] Students could collaborate with a partner asynchronously for this part of the project.

Proposal development also occurred online asynchronously. Each group produced their proposal and posted a proposal form on a discussion board for approval. The GTA reviewed proposals and provided feedback or approval. Groups used the GTA feedback to revise their proposals until they were approved. Most proposals obtained approval after two or three revisions, but some required as many as seven revisions to obtain approval. When the GTA approved a group's proposal, they assigned the group a data set for the investigation, and the group began its measurements and analysis. Based on our prior experience running the class, we prepared some data sets appropriate to the different proposals that previous students had produced and provided measurements to the current students in the most raw form possible to require them to make decisions about data collection and analysis.

The argumentation session was held in a scheduled Cisco WebEx session during the lab session the week after the proposal session. Before this session, each group was required to complete its analysis and create a three-slide presentation for the argumentation session. The first slide was a description of their measurements. The second slide was a presentation of the results, including a graph or table, and the third slide was their argument, based on their result. One member of each group gave the presentation, which was followed by questions. Students received credit for giving presentations, asking meaningful questions, and responding to questions. Following the argumentation session students submitted individual draft reports, peer-reviewed each other's drafts, and submitted final reports in the same manner used for the face-to-face investigations.

We administered the lab practical exams for both courses in Canvas using GlowScript simulations embedded in Canvas assignments. Students made measurements on the simulation and used their results to make an argument answering a guiding question.

B. Fully Online Laboratories–Fall 2020

Early on, we decided to hold our introductory physics laboratory courses online in the Fall 2020 semester in order to preserve the group class interaction aspects of ADI, which would be difficult under the social distancing requirements in place due to the pandemic.[14] Learning from some of the challenges we faced in the Spring, we informed the students before the course began that internet connectivity was required and that they must have access to a computer capable of running *Tracker*[12] and *ImageJ*.[11] We also included these statements in the course syllabus. Although we began the semester with the university open for socially distant face-to-face learning, that has since ended and we have pivoted to online instruction only for our undergraduate students.

Furthermore, so that we could provide students with a hands-on experience, we developed lab kits with supplies that allowed the students to perform the investigations outside the teaching laboratory. We purchased the lab kit items in collaboration with our campus bookstore, and the students purchased the lab kits from the bookstore. We ordered lab kit items in bulk and where possible directly from manufacturers to reduce the costs of the items. Each General Physics Laboratory I kit costs $\sim$\$25.00, and each General Physics Laboratory II kit costs \$39.00. And we have students paying for these kits in place of a physical lab manual, which we provide online for this course. The online adaptation of the face-to-face ADI curriculum has remained unchanged — pre-labs are done in small groups asynchronously, proposals are developed in larger groups asynchronously, and argumentation sessions are scheduled and occur via WebEx.

V. DISCUSSION

We have observed a great number of successes for these transformations. First and foremost, is that we indeed have a lab curriculum that is aligned with national goals and standards. Furthermore, we have successfully deployed this online with both short and longer planning times. Students are indeed engaging with science practices as determined by our practical assessments, and our department culture around laboratory course instruction is invigorated. Psychometric assessment of our students engagement with science practices is ongoing.

The transition to online learning has not gone without hiccups. Technology and access are two key factors for success in online learning environments, which were a barrier for many of our students. Indeed our institution's center for survey research has published some findings that explain some of our observed issues.[15] The GTAs and students found communication about proposals much more difficult online than in face-to-face classes. Indeed, about 10-20% of our students did not have reliable internet access after the transition to online learning in the spring.[15] Also, up to 8% of students did not have access to a computer once they left campus.[15] Additionally, we noticed that some students in the course did not have access to computers capable of running *Tracker* or *ImageJ*, both of which run on Windows, Macintosh, or Linux computers but not Chromebooks or mobile devices. We discovered *jsTrack*[16], an online Javascript web application for video analysis that runs on most computers including Chromebooks, but not mobile devices.

Many students could not or did not attend the online WebEx sessions or participate with their assigned groups. Once they left campus, many students found they had increased work or school responsibilities (42.1%) or additional family responsibilities (59.0%).[15] We removed non-participating students from groups and gave them an opportunity to make up their missed work asynchronously. Less than 50 % of the students in the make-up groups completed their work.

Finally, we hope these changes will be meaningful long-term as a lack of online labs is also a barrier for distance education students' completion of a degree. So online lab curricula would fill an institutional need.

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REFERENCES

[1] S. R. Singer, N. R. Nielsen, and H. A. Schweingruber, *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering* (National Academies Press, 2012).

[2] President's Council of Advisors on Science and Technology, "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President." Tech. Rep. (Executive Office of the President, 2012).

[3] American Association for the Advancement of Science, "Report on Committee on Science Teaching in the Public Schools," (1881), 1–12 pp.

[4] V. Sampson, J. Grooms, and J. P. Walker, "Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study," Science Education **95**, 217–257 (2011), https://onlinelibrary.wiley.com/doi/pdf/10.1002/sce.20421.

[5] J. P. Walker, V. Sampson, and C. O. Zimmerman, "Argument-driven inquiry: An introduction to a new instructional model for use in undergraduate chemistry labs," Journal of Chemical Education **88**, 1048–1056 (2011), https://doi.org/10.1021/ed100622h.

[6] J. P. Walker, V. Sampson, S. Southerland, and P. J. Enderle, "Using the laboratory to engage all students in science practices," Chem. Educ. Res. Pract. **17**, 1098–1113 (2016).

[7] J. Kozminski, H. Lewandowski, N. Beverly, S. Lindaas, D. Deardorff, A. Reagan, R. Dietz, R. Tagg, J. Williams, R. Hobbs, *et al.*, "Aapt recommendations for the undergraduate physics laboratory curriculum," American Association of Physics Teachers **29** (2014).

[8] A. Smith-Joyner and J. P. Walker, personal communication.

[9] S. F. Wolf, M. W. Sprague, F. Li, A. Smith-Joyner, and J. P. Walker, "Introductory physics laboratory practical exam development: Investigation design, explanation, and argument," in *Physics Education Research Conference 2019*, PER Conference (Provo, UT, 2019) pp. 657–663.

[10] J. P. Walker, A. G. Van Duzor, and M. A. Lower, "Facilitating argumentation in the laboratory: The challenges of claim change and justification by theory," Journal of Chemical Education **96**, 435–444 (2019), https://doi.org/10.1021/acs.jchemed.8b00745.

[11] C. A. Schneider, W. S. Rasband, and K. W. Eliceiri, "NIH Image to ImageJ: 25 years of image analysis," Nature Methods **9**, 671–675 (2012).

[12] D. Brown, "Video modeling with tracker," (2009), American Association of Physics Teachers 2009 Summer Meeting. Available at `https://physlets.org/tracker/download/AAPT_video_modeling_2009.pdf`.

[13] R. Chabay, D. Scherer, and B. Sherwood, "Glowscript.org," `https://www.glowscript.org`, Referenced 2020-08-16.

[14] A. McLoon and S. K. Berke, "A dry run at a socially distanced classroom," Inside Higher Ed (2020), published online at `https://www.insidehighered.com/views/2020/08/03/lessons-college-has-practiced-having-socially-distant-classes-opinion`.

[15] B. Edwards, P. L. Francia, and M. Van Willigen, "Ecu covid-19 impact survey: Reopening impacts on students and student adherence to pandemic protective practices." Tech. Rep. (ECU Center for Survey Research, 2020).

[16] L. Demian, "Motion tracking made simple," `https://jst.lucademian.com/info/`, Referenced 2020-08-16.