Introductory Physics Labs: A Tale of Two Transformations

First Author and Second Author

Masked Institution

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A key problem facing physics departments, especially given the current global pandemic, is how can we engage students in our laboratory courses while maintaining appropriate social distancing and hygiene standards. One solution to this problem is to move the labs to an online format. But how can we do this while *also* engaging our students in online labs with a curriculum that privileges science practices? We have created an intro physics lab curriculum that engages students in science practices and are implementing it online.

I. INTRODUCTION

Scientific truth is discovered through the practice of doing science. In fact, the National Research Council in it's report on Discipline Based Education Research (DBER) states, "Without [scientific] investigative practices, there would be no new scientific and engineering knowledge."[1] However, too often, laboratory courses do not meaningfully engage students in scientific practices, instead reproducing classical experiments.[2] This is part of a long-standing tradition of calling for authentic engagement in scientific practices which pre-dates Lorentz transformations.[3] Indeed, the AAAS stated our goals quite succinctly, "[Typical courses in t]he sciences. . . are not made the means of cultivating the observing powers, stimulating inquiry, exercising the judgment in weighing evidence, nor of forming independent habits of thought."[3]

The situation at our home institution in the Fall of 2016 very much mirrored the national narrative. The lab curriculum had been largely unchanged for about 20 years, and followed the traditional cookbook lab paradigm. Moreover, the equipment commonly used by students was outdated – triple beam balances and hand-drawn graphs were standard. In this 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. We will focus on the physics transformation in this paper.

We were satisfied with our progress when March 2020 rolled around, and with it, the mandatory shut-down due to the global 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've further adapted what we are doing so that students can still participate in a hands-on laboratory experience. We hope these changes will be meaningful long-term as a lack of online labs is also a barrier for DE students' completion of a degree. So online lab curricula would fill an institutional need. In the next sections, we will discuss our institutional and instructional contexts and describe each transformation in more detail.

II. INSTRUCTIONAL CONTEXT

This section needs to have the institution masked before we send it in.

East Carolina University is a regional master's 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 student population in Fall 2019 was 23k. Our physics labs (Physics 1 lab and Physics 2 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 Algebra-based physics lecture course. It also fulfills the general education requirement for science lab courses at our university. Table I compares the gender of students in these lab courses compared to the university population. We note that the gender distribution of students in the Physics 2 lab generally matches the university population, while the Physics 1 lab skews more heavily male than the university population. We also compare the race of students in these contexts in Table not ready yet...

Students who take these labs are most often science majors, especially in the health sciences (e.g., Biology, Exercise Science), but this lab is also taken by our majors. In Fall 2019 we had 409 students in the Physics 1 lab, and in Spring 2020 (at Census Day, before the pandemic changed enrollments) we had 256 students in the Physics 2 lab. In both labs, our enrollment is capped at 22 students, due to the constraints of our laboratory classroom.

Labs are supervised by MWS, but each section is run by Graduate TAs (GTAs). The transformed curriculum was jointly written by both of the authors. TA training was greatly enhanced when the new lab curriculum was put in place. SFW and MWS, 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. MWS runs a weekly prep meeting with the TAs, and SFW and the research team have supervised various aspects of the transformation especially important for research such as curricular implementation[?] and assessment practices[7].

Gender	Course		University
	Physics 1	Physics 2	
Female	41.8%	60.9%	57.1%
Male	58.2%	39.1%	42.9%

TABLE I. Gender breakdown of students in the Fall 2019 of the Physics 1 lab, the Spring 2020 Physics 1 lab, and the undergraduate poplulation of the university at large in Fall 2019. Note: The university only collected binary gender data

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. For example, in physics we often have students measure g using a well-known method (such as a spark timer). In ADI labs, we give students a question to answer (e.g., "Does the force a fan exerts on a cart depend on the mass of the cart?"), allow them 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.

A. Week 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 that I 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 reading 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 to do this work, 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. Week 2: Proposal Development and Data Collection

During this week, students work in groups of 4 to 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 (full credit for completing the proposal). However, this is the most critical week's for GTA training. GTAs have to be clear that the goal is to allow a diverse number of ways of collecting/analyzing this data. How much does the mass of the cart need to vary? How many different cart masses do the students need to take? How should students deal with friction? All of these are questions that we want the *students* to answer. And in some sense, we will be disappointed if all of the students come up with the same answer. Experimental methods certainly have an impact on experimental results.

C. Week 3: Argumentation and Peer Review

During this week, 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[8].

Students write 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 that 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 turn it in by the end of the day. Then, students take part in double-confidential peer review. We facilitate this online. They read and reply to two different lab reports. 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. We provide a rubric for lab report grading, and 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 East Carolina University, to move all their classes online. Our General 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. The face-to-face activities that we moved online were the Investigation 3 Proposal and Argumentation and the Investigation 4 Pre-Lab, Proposal, and Argumentation. In addition, we gave our laboratory practical exam online. We required student investigation groups to find a method for online collaboration in which everyone in the group could participate. Some groups used Cisco WebEx (video interaction platform licensed by our university) sessions, some used a group chat, and others used FaceTime or other online communication applications.

During the first week of online classes each group produced their proposal and it on a Canvas Discussion in a proposal form for approval. The teaching assistant (TA) reviewed proposals and provided feedback or approval. Groups used the TA 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. The TAs and students found communication about proposals much more difficult online than in face-to-face classes.

Investigation 3 in the General Physics Laboratory I course was a study of the periodic motion of a mass hanging from a spring in which the students were asked to determine when the spring's mass must be considered as a contribution to the period. Before the transition to online classes the students had completed a pre-lab activity in which they measured the period of a mass on a spring. For this investigation we provided videos of various masses oscillating on springs (100 oscillations each for 10 different masses and for the spring oscillating with no mass) and photographs of each spring and each mass on a balance. We posted video and photograph sets for six different springs so groups in the same lab section would each have different springs to study.

Investigation 3 for the General Physics Laboratory II course was a study of light diffraction in which the students were asked to determine whether hairs from two individuals had the same diameter. Before the transition to online classes, the students had completed a pre-lab activity in which they determined the width of a single slit by measuring the diffraction pattern. We collected hair samples from several people and posted photographs of the diffraction pattens of the hairs. Each photograph had a ruler at the bottom for the students to use as a length scale. We also provided photographs of the positions of the holder and screen on the optics bench. We gave the students a tutorial on using the ImageJ application[9] to measure distances in a photograph.

When the TA approved a group's proposal, they assigned the group a data set for the investigation, and the group began its measurements and analysis. We provided measurements to the students in the most raw form possible to require them to make decisions about data collection and analysis. Each group was required to complete its analysis and create a three-slide presentation for the argumentation session the following week. The first slide was a description of their measurements. Te second slide was a presentation of the results, including a graph or table, and the third slide was their argument, based on their result.

The argumentation session was held in a Cisco WebEx session during the lab session the week after the proposal session. 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.

Investigation 4 in the General Physics Laboratory I course was about collisions, and students were asked to determine whether a collision between two marbles was elastic. Our original plans were to have the students video marble collisions in lab and analyze them using the Tracker application[10]. When the labs went online, we provided the students with several videos of marble collisions and asked the students to install Tracker on their computers for analysis. We adapted the Investigation 4 Pre-Lab assignment so students could perform them on their own computers. The originally-planned pre-lab was an analysis of a video using Tracker. This activity required only a few changes from the face-to-face pre-lab assignment. We conducted the proposal session as described for Investigation 3 and assigned each group one of six videos of colliding marbles to analyze along with mass measurements of the marbles in the videos. The argumentation session and the remainder of the investigation were conducted in the same manner as Investigation 3.

Investigation 4 in the General Physics Laboratory II course was a study of radioactive decay. The pre-lab for the face-to-face course is a simulation of radioactive decay using dice in which the students roll several dice and remove all the dice with one dot showing. We wrote a GlowScript[11] program to "roll" randomized virtual dice so they could perform the same activity using this simulation on their computers. For the investigation the students were asked to determine which isotope was most common in the nuclear decay of a copper disk that had been exposed to low-energy neutron radiation. We measured radiation counts for several disks and also background levels and provided students with 30 s counts vs. time in CSV files for analysis. As in the other course, the investigation was conducted in the same manner as Investigation 3.

TABLE II. General Physics Laboratory I investigations for Fall 2020 block schedule.

Investigation	Topic	Guiding Question
1	1-D kinematics	Does a ball rolling on an incline have the same acceleration on the way up as it does on the way down?
2	Periodic motion	At what nut position is the period of the physical pendulum equal to 1.30 s?
3	2-D collisions	Is the collision between two marbles elastic?

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.

We encountered many problems with the move to online laboratories. Our students had not selected an online class, and many were not prepared for the sudden transition from face-to-face to online classes. Many students could not or did not attend the online WebEx sessions or participate with their assigned groups. Some students had to get jobs when they returned home, and others did not have access to high-speed internet. 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. We resorted to dropping the lowest investigation for the course.

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 such as smartphones or tablets. We discovered jsTrack[12], an online Javascript web application for video analysis that runs on most computers including Chromebooks. Students using mobile devices were not able to use jsTrack either.

B. Fully Online Laboratories–Fall 2020

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.[13] Also our teaching laboratories would have to operate at half capacity to maintain social distancing,

TABLE III. General Physics Laboratory II investigations for Fall 2020 block schedule.

Investigation	Topic	Guiding Question
1	Current and resistance	Does a light bulb behave like a resistor?
2	Time varying circuits	Do two of the lab kit capacitors have the same capacitance?
3	Diffraction of light	Are hairs from different people the same diameter?

preventing us from offering the courses to the necessary number of students. In addition to the social distancing requirements for face-to-face class meetings, our university adopted an eight-week block schedule, with the second block ending before the Thanksgiving holiday. Half of the Fall 2020 courses are scheduled for the first eight-week block, and half of the courses are scheduled for the second block. Course mapping between the originally scheduled 14-week semester and the two eight-week blocks was based on the originally scheduled class meeting time. In the block schedule, the one semester-hour lab courses have two two-hour meetings per week. We determined that even though there were enough lab meetings for the synchronous activities of four full investigations, there was not enough time between lab meetings for the asynchronous components and timely grading for four investigations. We reduced the number of investigations to three and added an additional pre-lab activity to each investigation. The topics for the three investigations and the guiding questions are in Table II for General Physics Laboratory I and in Table III for General Physics Laboratory II.

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 (General Physics Laboratory I) or ImageJ (General Physics Laboratory II). We also included these statements in the course syllabus. Although the courses were online, most of the students were on campus allowing them to access campus computer laboratories if they did on a computer that met the course requirements.

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 cost ???, and each General

TABLE IV. General Physics Laboratory I lab kit contents.

Quantity	Item	Investigation(s)
1	Protractor	1
2	25 mm marble	1, 3
1	Tape measure with cm scale	1, 2, 3
1	0.6 m threded rod	2
1	Eye nut	2
3	Nuts	2
1	Door hook	2
1	1 m string	2
1	16 mm marble	3

Physics Laboratory II kit cost ???. Table IV shows the lab kit contents for General Physics Laboratory I, and Table V shows the lab kit contents for General Physics Laboratory II.

V. CONCLUSION

SFW and MWS write this together.

We did it, and you can too! We should have a resources page/EPAPS for this paper.

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TABLE V. General Physics Laboratory II lab kit contents.

Quantity	Item	Investigation(s)
1	100 Ω resistor	1
1	330 Ω resistor	1
1	100 Ω potentiometer	1
1	E10 light bulb holder	1
1	5 V E10 incandescent light bulb	1
1	Breadboard	1, 2, 3
1	Breadboard power supply	1, 2, 3
1	USB power supply cable	1, 2, 3
1	Jumper wire set	1, 2
2	Multimeters	1, 2
1	Mini screwdriver for multimeters	1,2
5	500 mA fusses for multimeters	1,2
4	Alligator clip leads	1, 2
1	1 MΩ resistor	2
2	100 µF capacitor	2
1	5 V, 650 nm laser module	3
1	Tape measure with cm scale	3

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