Supplementary Materials: Introductory Physics Labs: A Tale of Two Transformations

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I. CURRICULUM DEVELOPMENT TIMELINE

Talk about the curriculum development, and how departmental culture around the labs changed as a part of this transformation.

II. ADDITIONAL 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 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 II. The racial and ethnic profile of students in our lab courses is similar to the university.

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 physics 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 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 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 SFW and the research team

	Course		
Gender	Physics 1	Physics 2	University
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.

	Course		
Race/Ethnicity	Physics 1	Physics 2	University
White	60.8%	60.8%	65.3%
Black or African American	17.1%	15.5%	16.3%
Hispanic	7.5%	8.7%	7.5%
Two or More Races	7.3%	5.3%	3.8%
Unknown	2.9%	3.0%	3.4%
Asian	4.0%	6.4%	2.4%
American Indian or Alaska Native	.	.	0.6%
Non-Resident Alien	0.4%	0.4%	0.6%
Native Hawaiian/Other Pacific Islander	.	.	0.1%

TABLE II. Race/Ethnicity breakdown of students inthe Fall 2019 semester of the Physics 1 lab, the Spring 2020 semester of the Physics 2 lab, and the undergraduate population of the university at large in Fall 2019.

have supervised various aspects of the transformation especially important for research such as curricular implementation[1] and assessment grading practices[2].

III. TRANSFORMATION #1: ARGUMENT DRIVEN INQUIRY

A. Physics I Investigation 1

B. Physics I Investigation 2

C. Physics I Investigation 3

D. Physics I Investigation 4

E. Physics II Investigation 1

F. Physics II Investigation 2

G. Physics II Investigation 3

H. Physics II Investigation 4

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 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 posted a proposal form on a Canvas Discussion for approval. The GTA reviewed proposals and pro-

vided 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. The GTAs and students found communication about proposals much more difficult online than in face-to-face classes. 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. We provided measurements to the students in the most raw form possible to require them to make decisions about data collection and analysis.

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[3] to measure distances in a photograph.

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[4], which is installed on the computers in the laboratory. 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[5] 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.

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 registered for an online class, and many were not prepared for the sudden transition

TABLE III. 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?

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 many students 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*[6], 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.[7] Also our teaching laboratories would have to operate at half-capacity face-to-face to maintain social distancing, 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 were scheduled for the first eight-week block, and half of the courses were scheduled for the second block. Course mapping between the

TABLE IV. 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?

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 III for General Physics Laboratory I and in Table IV 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 costs ∼$25.00, and each General Physics Laboratory II kit costs $39.00. Table V shows the lab kit contents for General Physics Laboratory I, and Table VI shows the lab kit contents for General Physics Laboratory II.

TABLE V. 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

TABLE VI. 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 fuses 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

REFERENCES

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