The Physics Teacher

PAPERS | SEPTEMBER 01 2021

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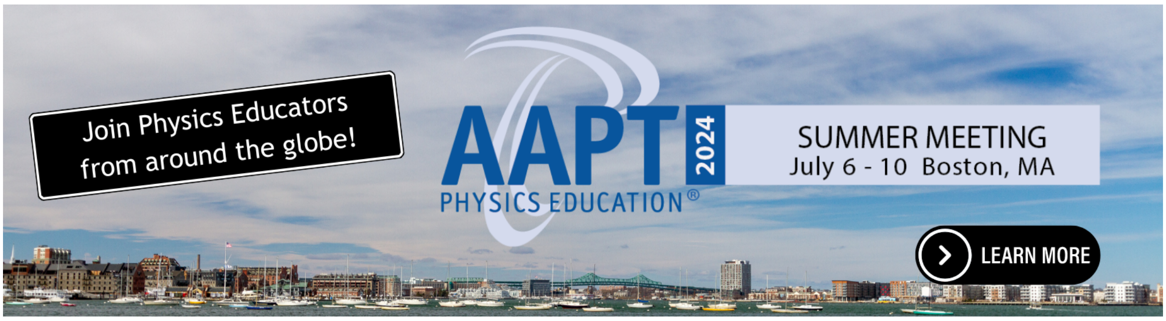
Kathleen Koenig; Sarah Bake



*Phys. Teach.* 59, 394–396 (2021)
https://doi.org/10.1119/5.0039606





# Maintaining Essential Course Features When Moving Introductory Physics Labs Online

**Kathleen Koenig and Sarah Baker,** University of Cincinnati, Cincinnati, OH

The sudden transition to online teaching due to the pandemic in spring 2020 provided us the opportunity to experience firsthand the challenges involved in delivering labs online. After learning that our introductory lab courses would be taught online fall 2020 and spring 2021, which involve over 2200 students, the decision was made to invest significant effort into redesigning the labs for online delivery, and this effort became part of the teaching load for the first author. This paper discusses the decisions made, innovations implemented to maintain essential features of our in-person labs, and lessons learned.

## Introductory physics labs

Through NSF funding, our first-semester algebra- and calculus-based physics labs were designed to promote student abilities in scientific reasoning. All activities are organized around a central research question that explicitly targets causal and hypothetical reasoning embedded in cycles of inquiry, reflection, evaluation, and communication of outcomes. The learning goals emphasize science as a process, and students collaborate to design and conduct six investigations across 12 weeks (two hours/week). Results are shared between groups, often culminating in the development of a mathematical model, followed by application to predict outcomes.

The curriculum has multiple parts. Pre-lab instruction introduces key concepts or skills, while providing deliberate practice in hypothetical situations.[1] In-class investigations provide more authentic practice, with activities scaffolded such that students become better able to address more complex research questions within more complex contexts. Designated checkpoints engage students in Socratic dialogue with the teaching assistant (TA), a process well supported in the literature for developing scientific reasoning and conceptual understanding.[2] Lab report writing is heavily emphasized, and detailed grading rubrics award points for behaviors sought. More detail can be found elsewhere.[3]

Our second-semester algebra- and calculus-based labs involve topics that are much more abstract, such as electric fields. These labs were designed to address common student misconceptions through guided hands-on exploration, similar to other research-validated materials.[4,5] While these labs also involve pre-lab instruction and practice, rather than lab reports students complete follow-up homework exercises through Canvas, our course management system.

## Modifying labs for online delivery

As we considered the redesign of our labs for online delivery, we decided to maintain the in-person curriculum and develop parallel materials for online use. We felt this provided more flexibility moving forward, while addressing a previous need for materials for students who miss multiple labs for extenuating circumstances. Because pre-lab instruction was already delivered through Canvas, few changes were needed. For the in-class portion, we identified features that we believed were absolutely essential for course effectiveness based on our prior experience teaching the labs,[3] the research literature,[2,6,7] and the AAPT Lab Guidelines,[8] including the need for students to (1) work in collaborative groups, (2) make decisions as they designed experiments and collected data, (3) engage in Socratic dialogue with their TA to facilitate understanding, and (4) share evidence-based outcomes with other lab groups. These features primarily involve course delivery, so we were able to maintain the core of the weekly lab instructions, assignments, and grading rubrics, while changing the mechanisms for how the course was conducted, which are described here.

## Use of Zoom breakout rooms

The use of Zoom, a video communications platform, was key for supporting collaborative group work. Each lab class began in the main room, where a single TA provided up to 32 students an overview of the activities to assist navigation. Students then worked in Zoom breakout rooms in groups of three to four, which remained the same after allowing for self-selection the first week. Each group worked through the lab instructions, collected data through videos or simulations (described later), analyzed data in Excel, and documented all work in a Word file. Given the number of applications, students took responsibility for one of these and shared their screens as needed. At designated checkpoints or when help was needed, groups used the "contact your instructor" feature, and a pop-up window alerted the TA, who then dropped into the breakout room to address questions or engage students in Socratic dialogue to check the reasoning behind their work. One advantage of Zoom is that names appear on the screen, so TAs could call on different students during these conversations, making it more personable and inclusive.

## Use of prerecorded videos and simulations

An integral part of our first-semester labs involves providing students with many opportunities for making and justifying their own decisions, including those involved in experimental design and data collection. Given our large enrollment, we were unable to send equipment to students. Instead, for some experiments we made a collection of videos for various conditions from which students could select. For example, for investigating "What impacts the period of a pendulum?" we created over 40 videos involving pendulums with different lengths, masses, and angles of release, with each video including 12 full swings. Using this format, students had to decide which videos to include in their data collection, how many swings to time to minimize error (cell phones were used as stopwatches), how many trials to include, etc. Another investigation addressed the question "What impacts the period of a



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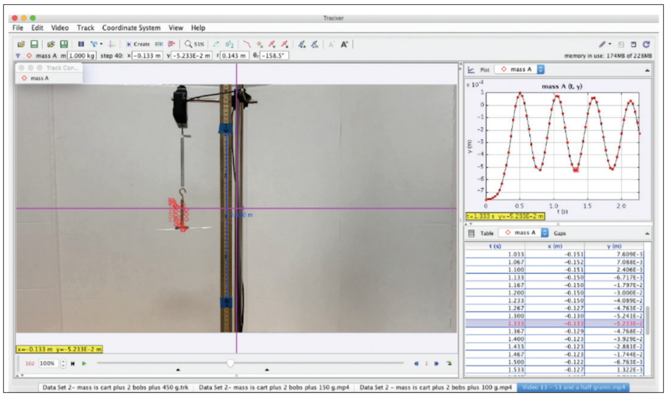

Fig. 1. Screenshot of Tracker with embedded experimental video of mass oscillating on a spring. Analysis of the data is on the right.

spring/mass system?" Here, we created over two dozen videos for three different independent variables, including spring constant, hanging mass, and distance of pull, and students engaged in many of the same decisions as the pendulum lab. However, rather than use cell phones to determine the period, students used Tracker,[9] a free video analysis tool, which reduced error in the data (Fig. 1). Subsequent labs followed the same format and used Tracker, but due to a lack of space detail is not provided here. However, those interested can request free access to all materials by contacting the author. Our final lab, a design challenge in which students created a wind turbine given criteria for energy output and cost, was conducted through a downloadable simulation.[10] Our second-semester online labs only involved the use of freely available simulations, with many selected from the PhET website.[11]

## Use of Microsoft OneDrive to monitor student progress and provide feedback

One challenge with online labs is that TAs cannot walk around and listen in on students' conversations and intervene, if necessary. Although a TA can periodically drop into a breakout room, their appearance can be disruptive and doesn't allow for listening in. A work-around was the use of Microsoft OneDrive, a file hosting service where TAs created a separate folder for each of their classes. Within these, TAs created folders for individual lab groups as well as a class folder. Students' work was completed using documents generated in the group folders, allowing all students to simultaneously contribute to the documents, while also providing a place to save items for future use.

Given this setup, it provided TAs the ability to view each group's work as it was being generated. To facilitate this process, each group's document(s) could be opened in separate tabs at the beginning of class, making it easy to click through and continually monitor groups throughout the lab session (Fig. 2). It also provided a mechanism for TAs to provide feedback as they could type directly onto the document using a different color font. For example, as shown, the TA provided reassurance that students were on the right track with the comment "Graph looks great!" while also providing direction with "How might you show measurement uncertainty on the graph?" Although it took a few weeks for TAs to become comfortable and proficient with this process, one unexpected advantage was that TAs could catch errors in experimental designs, graphs, and claims in between the checkpoints. This reduced the load on the TAs during subsequent checkpoints and decreased time spent grading students' work after class.

The class folder was used for sharing groups' claims, typically in the form of mathematical models. In these instances, a table created in Word was posted for groups to enter requested information (Fig. 3). The TAs monitored the document and, when complete, students were called to the main room using a feature in Zoom. The TAs shared their screens and used the table for a wrap-up discussion, allowing students to resolve inconsistencies, some evident in the table shown, while guiding students to evidence-based claims given certain conditions. Students later downloaded an updated table for use in their lab reports.

## Mid-term student surveys

All students were given a mid-term survey, and responses were similar across courses. Students were asked to select their preference among three lab formats, where 88% (735 students) selected "synchronous, group format implemented this term," 9% selected "individual, asynchronous format," citing the need for more flexibility due to other commitments, and 3% selected "individual, synchronous format with TA access." Given this feedback, we will maintain our current structure in the future.

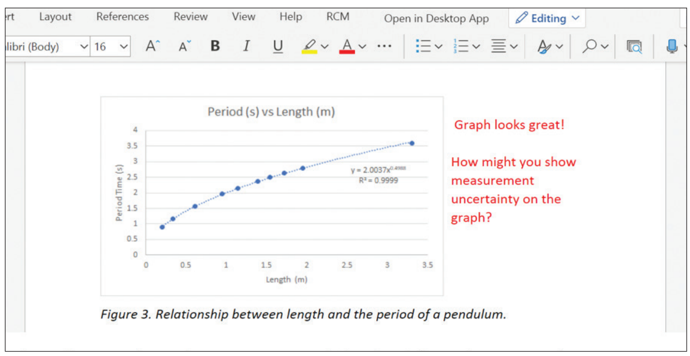


Fig. 2. Screenshot of a group's work on OneDrive with feedback from the TA in red.

| Group Number | Experimental Model (with units on constants) | Control Variables with values used (for IV=length experiment only) |
|---|---|---|
| 1 | T = (2.0012 s/m) $(L)^{0.4995}$ | 0.09 g = mass of pendulum<br>20 degrees = angle of release |
| 2 | T = 2.004(sec/m) $L^{0.5016}$ | 0.05 kg = mass of pendulum<br>15 degrees = angle of release |
| 3 | T = 1.9609 $L^{0.4957}$ | 250g = mass of pendulum<br>15 degrees = angle of pendulum |
| 4 | T = 2.0075 $L^{0.4957}$ | .05 kg = mass of pendulum<br>20 degrees = angle of pendulum |
| 5 | T = 1.9966 $L^{0.4974}$ | 0.05kg = mass of pendulum<br>10 degrees = angle of pendulum |
| 6 | T = 2.0037 $L^{.4988}$ | .9 kg = mass of pendulum<br>10 degrees = angle of pendulum |

Fig. 3. Table used for groups to share outcomes in Class Folder on OneDrive.

When asked an open-response question about challenges encountered in the online lab, most indicated none, while others cited (1) technology issues, such as loss of internet, (2) group accountability, where not all members contributed equally, (3) difficulty explaining themselves given the online environment, and (4) having to wait for the TA once called to the breakout room.

When asked an open-response question about positive course features, many mentioned group work, indicating this made the labs more enjoyable, improved learning through sharing of ideas, and provided a more comfortable setting for asking questions. Others liked group work followed by class discussions, with one student claiming it "lets us do the learning by ourselves first." Others appreciated the course structure, clear course expectations, consistent pattern of weekly assignments and due dates, use of pre-lab to set the stage and use lab time more efficiently, and grading rubrics for self-assessment. A few mentioned the synchronous class format helped them keep up with the required work and stay connected.

## Lessons learned

In addition to what has been discussed, we attribute much of the course success to the organization of the materials on Canvas, which provided structure for the students and TAs. We strongly recommend consulting with the literature on best practices in online instruction during the course development process. We also note the importance of surveying students early in the term so adjustments can be made, as many survey outcomes were not readily apparent. For example, based on students' concerns over group participation, we began to use a post-lab survey via Canvas each week so students could indicate whether they were satisfied with their group's contributions. Those answering "no" were asked for more detail. TAs used this feedback to inform student's weekly participation scores, where points had previously been awarded based on TAs' observations alone. This also helped us recognize that some students' apparent lack of effort was due to not knowing how to contribute in the online environment. In the future, we will formally assign roles to students, describe what the roles entail, and rotate roles each lab.

Last, TA training is critical. Although our TAs have always participated in weekly 90-minute training meetings, it became even more important here. TAs needed the full student experience, from working through the lab materials with up to three other TAs in the breakout rooms, to holding "class" discussions with the author (trainer). TAs needed to experience what it was like to collect data using the videos and simulations, and navigate group work with multiple applications involved. We also noticed that TAs' comfort level with online instruction improved across the term, and the conversations and support provided in the weekly meetings played a significant role.

## Conclusion

While we can't claim that online labs have the same benefits as in-person labs, we feel that we were able to address the same set of learning outcomes, while providing students with engaging learning experiences. We also believe that we provided students with similar opportunities for making decisions and justifying evidence-based claims, while maintaining the rigor and essential features of in-person labs. One measure of our success includes weekly attendance, which was over 98%, similar to our in-person labs. Another measure involves the percent of students earning a D, F, or withdrawing from the course. This was ~5% for all sections, lower than the ~7% for our in-person labs. We will continue to make improvements as labs are offered online during the pandemic.

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**Kathleen Koenig** *is a professor of physics at the University of Cincinnati, with her research in physics education. She has extensive experience and external funding for the development and evaluation of pedagogies and curriculum that support student success in college-level science and math courses.*
**koenigkn@ucmail.uc.edu**

**Sarah Baker** *is the lab coordinator for the Introductory Physics Lab courses at the University of Cincinnati. As part of her work, she plans and conducts the weekly training for the graduate teaching assistants who teach the lab courses.*