Out of the Lab and into the Living Room: Restructuring an Optics Lab for Remote Learning amidst the COVID-19 Pandemic

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Introduction

The year 2020 has brought with it many surprises, perhaps the most widespread and life-altering of which is the COVID-19 pandemic. In March of this year, most universities converted their classrooms to online spaces, allowing students to complete their studies via remote learning throughout the remainder of the spring semester. In the United States, the end of the pandemic is nowhere in sight as of August 2020, so many universities plan to continue their online classes into the fall semester, including lab courses. In general, college courses can be converted to an online format without fear of students losing out on too many skills a course aims to cultivate within them; however, the same cannot be said for lab courses. They generally require special, expensive equipment that students do not have access to without also having access to their college campus. Unless they are able to use such equipment, data cannot be collected or analyzed, which is of course the core of a lab course. Thus, online learning critically restricts the educational ability of courses taking place in the lab. However, these courses and the skills learned through them are vital to a physicist's education. It is important, then, to consider ways of compensating for this educational deficit presented by online learning.

The goal of my project is to address these needs. A solution for this predicament supported by Dr. Jennifer Ogilvie, a physics professor at the University of Michigan and my advisor throughout this project, is to create lab activities specially designed for at-home completion. Though this cannot be done for every experiment in a weekly lab course on such short notice and on a limited budget, modifying at least one experiment to fully compensate for distance learning would give students the opportunity to develop foundational skills for working within a lab environment. Thus, in my project, I completed a multitude of tasks to build upon previous work to restructure and rewrite a lab to allow for students at home to sharpen their laboratory skills.

This summer, I worked with Cameron Spitzfaden, a physics PhD candidate at Michigan, under the supervision of Dr. Ogilvie to complete this project. The lab we chose to modify is a diffraction and interference themed experiment that is a part of the class, PHYSICS391: Introduction to Modern Physics Lab. Together, we discussed potential activities, identified equipment to use in such activities, and set learning goals. From this, we wrote a lab manual for the experiment and assembled a kit of inexpensive materials to send to every student enrolled in the course to allow them to complete the lab. We produced a lab which is affordable and fully accessible from home, and that investigates the majority of the phenomena the original lab covered. Though the students enrolled in this class will not be able to enter the lab, they will be able to build the skills necessary for future work in such settings.

Learning Goals

Before designing the activities, we discussed what skills we wanted the students to take away from the lab outside of those specifically related to the physics topics they were to explore. Drawing upon the criteria proposed by the American Association of Physics Teachers for undergraduate laboratory curriculum, we decided upon three skills we wanted to sharpen.

- First, we wanted them to develop their sense of **independence in the lab**. Physics students should feel comfortable performing a variety of tasks in the lab, including experimental design, data collection, and analysis. We decided to encourage this by avoiding step-by-step instruction, instead leaving them to use their own intuition to perform all the necessary actions to make measurements and observations.
- Second, we wanted them to leave the lab more knowledgeable about **using models** to understand physics phenomena. To do this, we devised experiments which asked them to make measurements and model their data. From these models, they are required to make meaningful conclusions.
- Finally, we decided to emphasize **communicating physics**. This was achieved by requiring students to answer questions in addition to reporting their quantitative results. Throughout the lab, they are asked to make observations and explain them, giving them the opportunity to practice writing about physics phenomena.

Additionally, one application related specifically to light that we wanted them to grasp is the usefulness of diffraction in determining structures. To do this, we asked them questions about how the shape and size of the slides/objects used to create the diffraction patterns affected what they observed. We also detailed real situations in which diffraction is utilized to learn new information about structures. This allowed them to learn more about the widespread application of diffraction in observing molecules and other small structures.

Methods

Activity Creation

Before deciding which activities to incorporate in the lab, we discussed which physics phenomena we wanted the students to explore. Inspiration for this was drawn from the original PHYSICS391 diffraction and interference lab, written by Carl W. Akerlof. From this document's experimental design, we decided that it was important for the students to learn about the diffraction patterns due to slits and other shapes, Babinet's principle, thin film interference, and diffraction gratings. Much of the original lab required sophisticated equipment to explore these topics, such as lenses and apparatuses for making difficult observations. We thus had to be creative in how to work around the limitations of remote learning in our own experimental design, using only inexpensive equipment or materials common enough that they could reasonably be found in most houses, to investigate the same phenomena.

Once the topics were chosen, we devised specific activities which explored them. To find inspiration for potential activities, we used journals such as *The American Journal of Physics* to identify previous activities used by physics educators. We also referenced the original lab, discussing ways of simplifying the experiments so as to not require sophisticated equipment. From these searches, we created a list of activities to try. We then identified equipment we would need for the activities; for example, I found the laser pointer which we decided to purchase for the kit sent to the students. Before purchasing materials in bulk for the kits, we purchased only enough for mine and Cameron’s attempts at completing the activities we designed.

One activity we desired for them to complete, but could not easily fund, was a single slit diffraction experiment. Single slit slides were too costly to purchase in bulk; however, this concept was important enough that I decided to attempt to create one from household objects. I was able to do so by using aluminum foil, matte scotch tape, an X-Acto knife, and cardboard. Slides have previously been designed for single use from home by cutting aluminum foil; however, my design was purposed for durability. Durability was important because the slides needed to be able to be sent in the mail to students and still be fully functional. I found that by taping the aluminum foil over with matte scotch tape, the foil was much more likely to hold its shape when handled. This was enhanced by encasing the foil in a window of cardboard on both sides. This single slit is able to be easily and cheaply made by hand, but it still easy to use. The diffraction pattern created by the slides are clear and large enough to use for data collection. An example pattern can be seen in Figure 1.

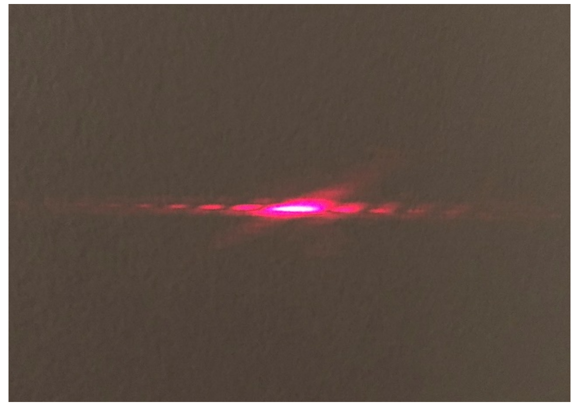

Figure 1 An image of the diffraction pattern created by the handmade single slit slide.

Another activity of note is the use of a ruler to create a diffraction grating. If a ruler’s scale is printed on its surface, it can be used as the grooves of a grating if the incident light is shone at an angle very small when measured off the ruler. This was first reported by A. L. Schawlow in *The American Journal of Physics* in 1965,[1] and we used many of the ideas described in his article to create our own version of this activity for use in the remote PHYSICS391 lab.

<u>Integrating Online Sources</u>

Once we had developed the activity ideas, the only topic which we felt was missing from the lab was observing the effect that wavelength has on diffraction. Our budget only allowed for one laser to be sent to each student, so our activities could only show the students patterns due to one wavelength of light. Thus, we explored other options. The most favorable was the use of a simulation published by the University of Colorado Boulder entitled “Wave Interference.”[2] This simulation, which is published under the Creative Commons Attribution license as a part of the PhET Interactive Simulations project, shows a laser shining through an aperture and onto a target (see Figure 2). It allows the user to explore diffraction patterns interactively by varying parameters such as aperture shape, shape

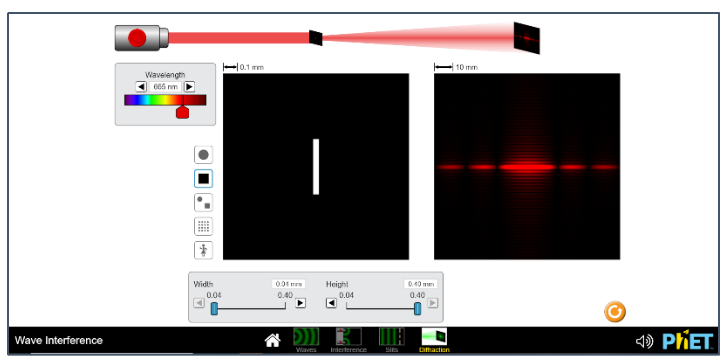

Figure 2 A screenshot of the PhET simulation utilized by this lab.

size, and, most importantly, the wavelength of light produced by the laser. This simulation was integrated into the lab such that it supplemented the missing topic of wavelength's impact on diffraction patterns. It was also used to allow students to acquaint themselves with some of the patterns they would create themselves.

Testing the Activities

Once the activities were chosen and the materials were compiled, Cameron and I began to test our ideas. First, I created and tested the single slit slide design mentioned above. This was successful, and I was able to take data to determine the width of the slit. Similarly, a strand of hair was used to successfully create a pattern, and I collected data to measure its width. I also tested the ability for a bubble to be used to observe thin film interference with a keyring and dish soap; like the single slit slide, this was successful. Cameron successfully created the diffraction pattern of a small coil using the spring from a pen. Finally, the pattern from a ruler's scale was created with a reasonable amount of effort. Though several other activities were proven too difficult to be included in the report, we were successful in designing activities which touched on nearly every topic we had hoped to cover in the lab. As we tested the activities, we took notes concerning how to best complete them, which I later used to inform the directions included in the lab manual.

Creating the Lab Manual

One of my largest tasks was to write the majority of the lab's content. To write the lab, I referenced the notes created by me and Cameron, reviewed related physics concepts to ensure accuracy in my explanations, and completed additional tests of the activities to identify necessary safety warnings. The content which was not written by me was copied from the original manual with the permission of Carl Akerlof or written by Cameron and Dr. Ogilvie. Revisions were completed by me, Cameron, and Dr. Ogilvie over the course of several weeks before bringing the draft to the other faculty members teaching the course in order to gain their approval.

Another prominent task was to create diagrams for the lab. For this, I used Microsoft's Paint 3D program. I created diagrams showcasing proper experimental setup and models for physics phenomena. The diagrams were created using photographs, mathematical functions plotted in Mathematica, and shapes easily created within the Paint 3D program. This program contains several tools which were particularly useful, including the "Magic Select" tool and the ability to make items 3D. See Figure 3 for an example of a diagram I made using this program.

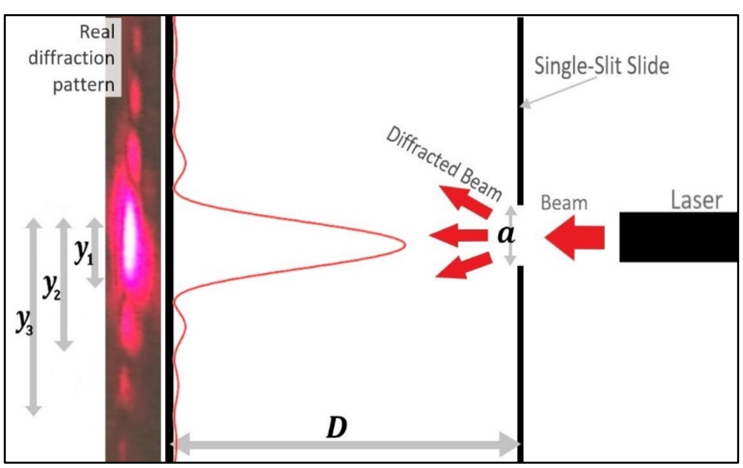

Figure 3. A diagram I created which shows the proper experimental setup for the single slit diffraction activity.

Content

The lab opens with an introduction to the material and safety precautions concerning the laser. Next, they are shown background information about diffraction and the math which guides the phenomenon.

The lab's activities begin with the PhET simulation. The students explore how diffraction patterns depend upon shape, dimension of aperture, and wavelength. They also perform a calculation to determine the distance between the slide and the target in the simulation. They are asked to determine whether their observations are consistent with the background information provided in the introduction. This section emphasizes the learning goal of **communicating physics**, because we require them to answer questions about and explain connections between the theory they have learned and the phenomena they observe.

Next, they use the single slit slide and the 650nm laser to determine the width of the slit. This is accomplished by taking data measuring the distances between the bright center of the pattern and the dark fringes. After this, they confirm Babinet's principle by creating a diffraction pattern using a strand of hair. They are asked to take data to calculate the width of the hair in the same manner as with the slide. This section encourages them to learn how to better **model physics data and phenomena**, as they must use scatter plots and lines of best fit to analyze their data. They will also grow their sense of **independence in the lab** through these activities because the minimum amount of instruction is given to aid them in setting up their experiment. Instead, they are prompted to devise their own experimental setup.

Next, they explore two more diffraction patterns. First, that of a small, circular hole. They are asked to create the hole themselves with aluminum foil using a thumb tack. Then, they use a small coil to look at the pattern of a helix. This pattern is compared to that of DNA in the manual. This comparison emphasizes the **usefulness of diffraction in determining structures** which would otherwise remain mysteries. Other information is provided to strengthen this learning outcome.

The final pattern they create is that from the scale of ruler, which acts as a grating. They are asked to take data on the pattern they create, and from this information determine the wavelength of light produced by their laser. This section emphasizes **all three of the general learning goals**, as they are asked to devise their own experimental setup, model their data, and answer questions about their observations.

For the lab's conclusion, they explore interference using a bubble. They must create a bubble using soap and a keyring. This activity will sharpen their ability to **make models**; they are asked to think critically to formulate the mathematical equations which describe the thickness of a film necessary to create destructive interference or constructive interference. This exercise will allow them to practice applying mathematics to a physics phenomenon to better understand it and make predictions for other situations. They will also better learn to **communicate physics** because they must explain how they determined what these equations are. Further, they will answer questions about thin film interference based upon what they observe the bubble to look like.

After the activities of the lab conclude, the manual contains several appendices. First, an appendix detailing tips which might aid them in setting up their experiments. Next, we provide possibly useful online links for their own exploration outside of the lab. For example, a link to a paper detailing how a singular photon interacts with a double slit experiment is provided. The third appendix is an explanation on uncertainty in measurements, in case they are unsure of how to calculate uncertainties for more complicated equations. Finally, an appendix showing the diffraction patterns of higher-ordered slit slides is featured.

Conclusion

As of August 7th, 2020, approximately 65 students are enrolled in the PHYSICS391 course for the upcoming fall semester. These students will receive both the kit and manual, and they will complete the full lab. In my future career, I plan to create educational physics materials, so I hope to hear feedback from the instructors concerning the lab's efficacy and reception. Hearing the students' reactions to what I have helped create this summer will allow me to inform decisions I make when I write additional educational resources. Further, their feedback can guide any future revisions to this project. Our group hopes to publish the work we have completed in a physics education journal, so student reception can shape any changes we make before publication.

I learned many skills throughout this program. First, I learned how to work with a team to reach a common goal within a research context. I have completed research projects on my own, but this is the first team I have worked closely with. In the future, I will be better prepared for collaboration on similar projects, as well as for larger projects involving many collaborators. I also learned how to self-monitor my progress as I worked on my own. Since the program was held remotely, I had to keep track of my tasks and make sure I was accomplishing my goals on time. This has helped prepare me for my future as a graduate student because I will be able to more easily make a habit of fulfilling my responsibilities in a timely manner. One other skill I learned is the ability to work within a budget. We had to be careful with the amount of money we spent, and this drove me to think creatively when deciding how to design the activities. For example, choosing to create a slide from home instead of buying single slit slides allowed us to include the single slit diffraction activity at a fraction of the cost. Someday, I will need to adhere to similar guidelines when managing my own research as a professor.

References

1. A. L. Schawlow, *American Journal of Physics*. 33, 922 (1965)
2. The University of Colorado Boulder, *PhET Interactive Simulations*, <https://phet.colorado.edu/> (2020).