Creating Accessible Spaces For Experiential Learning In An Online Environment

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The switch to online learning required a creative solution to allow for the experiential learning outcomes of the program to be satisfied when access to physical spaces and equipment was restricted. This paper describes a collaborative process between technical and support staff as well as research and teaching faculty that led to the creation of meaningful experiential learning opportunities for over one thousand stakeholders. The implemented solutions included the development of hardware and software, the creation of documentation and training procedures for teaching assistants and designing a support system for the students.

Hands-on experiences in science laboratories are crucial to a learning process for science majors, especially those pursuing a degree in physics, as they force the engagement of various levels of knowledge into decision-making (Millar et al., 1994) and aim to expose students to practices and methods used by scientists (Otero & Meltzer, 2016). While in need of critical evaluation (Holmes & Wieman, 2018), and not always directly contributing to students' performances in the courses (Wieman & Holmes, 2015), several types of the laboratory experiences affect the gains and depth of student learning (Bernhard, 2018). The switch to the online learning mode during the COVID-19 pandemic placed an Everest-sized challenge in front of those, who plan, develop, and deliver the laboratories, when they were tasked with satisfying the experiential learning outcomes of the programs while students' access to the physical space and equipment was denied. Without any previous experience in the remote teaching environment, the approach to the development of the alternative experiential learning opportunities for the students commenced by collectively creating an interuniversity taskforce that met multiple times to share ideas and resources.

The teaching team from the University of Athabasca already had extensive experience delivering laboratories that could be done at home within their long-standing distance education program which made them invaluable in the process. The result of this collaboration was the development of a set of laboratories for courses that cover mechanics (using household items),

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waves and optics (using kits assembled by the technical team), and modern physics (using guided recordings and data sets). To ensure that the laboratories were accessible to all students not a requirement and online laboratories, which relied on the live streaming, had a low-bandwidth option.

At Home Laboratories

The laboratories associated with the mechanics course were realized by designing two-stage experiments with the first part completed individually by the students at their homes and the second part done in small teams during a scheduled laboratory session. The individual part was designed for the student to set up the experiment, carry it out and make a real-time recording of it happening with any available device. All experiments were devised keeping in mind the fact that supplies available to the students and their budgets may be limited, therefore they relied on items that were readily available in homes and dormitories and had many suggested alternatives. The student-created recording was then processed using a video analysis software written by one of the authors and made available for the students enrolled in the courses on the departmental website. The software, which was designed to be robust, intuitive, free, and not require any sophisticated equipment, was accompanied by a video tutorial that guided students through the steps of data gathering and transfer. The experiment-specific spreadsheet templates were provided for both the individual and group parts of each exercise. The last step of the individual assignment required the students to copy their data to the excel template and perform a simple analysis (notice and report trends and comment on both expected and unexpected results). The individual portion of the experiment was graded for completion (submission of the video) and relevance of the answers provided in the attached spreadsheet. While the experiments were to be completed at home, the teaching assistants assigned to the course held office hours during the week, usually aligned with the scheduled laboratory session, to allow for student questions and help trouble shooting laboratory challenges.

The group part of the laboratory had students meet in virtual spaces to discuss their observations, choose one of the data sets and analyze the collected data, including curve fitting and uncertainty estimation. The findings of the group work were recorded in a shared template, that guided the students through the process. During the group meetings, the teaching assistants were available in the virtual spaces, visiting groups in their breakout rooms, and providing any help that could be required.

Realizing the unusual character of the learning environment, an ethics board approval protocol was submitted and approved to collect student self-assessments of their progress in the labs. The data collection and analysis became a capstone project (Dhaliwal, 2021). Throughout the Fall 2021 semester the students who chose to participate in the study completed a series of surveys, self- reporting their confidence levels regarding the skills associated with each laboratory. The results showed that the students reported a slight increase in their overall confidence regarding their general skills as well as a comparable boost regarding their awareness of the experiment-specific skills and knowledge (Dhaliwal, 2021). Unfortunately, there has never been a similar study conducted during the in-person laboratories so no reference or comparison is available. Laboratories for which the experimental kits were assembled and shipped to the students followed a similar structure.

Remote Laboratories

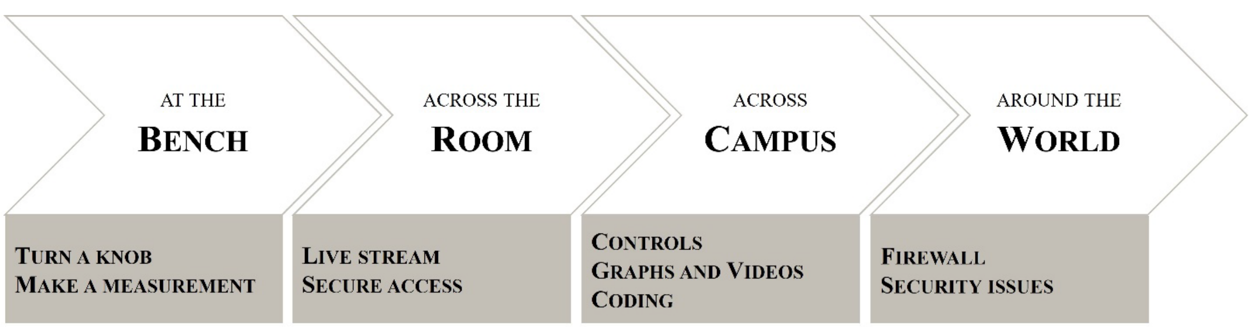
Topics in electricity in magnetism presented a challenge on a larger scale. The commercial kits that could be used safely by the students were not suitable for the content and level of the courses they were required for. While we found suitable replacements for some exercises using simulation software available online (Falstad, 2023; University of Colorado PhET Project Team, 2023), they were not sufficient to address the course outcomes related to the operation and control of the laboratory equipment, experiment planning, and collection of imperfect data in real time. To surpass the opportunities provided by the easily accessible simulations, the product that we wanted to offer to the students had to be interactive, address the two missing elements, while being simple in operation, reliable, and robust. While the design details varied, issues related to bandwidth, readability (size and type of font, closeness of displays), clarity (colour choices, location of buttons, communication, and feedback provided to the users), comfort level with operating equipment (range of variables that could be set up, promptness required, ability to reset and restart) were always addressed.

Designing of the First Lab

Our transition of the experiment from a classic laboratory set up to a remote one started with figuring out whether we could automate or control our physical equipment through a computer. Originally the response to that question was negative, however by breaking down the problem into smaller, incremental steps we were able to achieve a working solution. Figure 1 depicts the process undergone to create the first iteration of the remote labs, together with the key challenges that needed to be overcome at each phase.

Figure 1

A schematic of the laboratory development process with the challenges and tasks faced at each stage



The initial step (at the bench) was to determine whether we could actuate a knob on an apparatus (specifically a power supply) and record data from a sensor. We achieved a positive result at this level by using open-source programmable microprocessors (Arduinos) to control stepper motors and an adapter that allowed the microprocessor to collect the data from the sensor.

The next challenge (across the room) was to implement a way for a person to see the equipment in real time when they are not in the vicinity of it and, consequently, create a way to securely access the video stream used for that purpose. A pipeline was also created to push data from a local computer and display it on a website for potential users. An open-source software, originally designed for surveillance devices, was used to create a secure video stream that integrated with webcams set up in the laboratory.

To ensure the users could interact with the experiment from any place on campus (across campus), the web interface was built. The initial infrastructure, that consisted of a video stream and the control area, was subsequently modified to address feedback provided by the testers and suit the growing and evolving needs of the laboratory design. A screenshot of the interface available to the students is shown in Figure 2. In addition to the visual of the equipment and the information about the workstation (bench number, users logged in at the station), current equipment settings, and the log of all the actions taken by the users were included. The system was designed to allow for the addition of any number of workstations (benches), with each group being able to see and operate their own equipment.

Additionally, this design allowed us to incorporate a way to graphically display data being collected by the microprocessor-controlled sensors to improve the student's ability to identify trends in the data as they adjusted the experimental parameters. This step was also used to build functionality that allowed the technical staff to remotely turn on the livestreams, and equipment on the benches at the university, including computers and lights.

The final phase was to ensure that the website and, more importantly, the livestream and controls were accessible from beyond the university as many students were living in other cities, provinces, or even countries during the pandemic (across the world). Through coordination with the Information Technologies Department, we were able to establish a reliable way to access the website from any location in the world while maintaining the integrity and security of the university's network allowing only authorized users to access the virtual space.

Interface

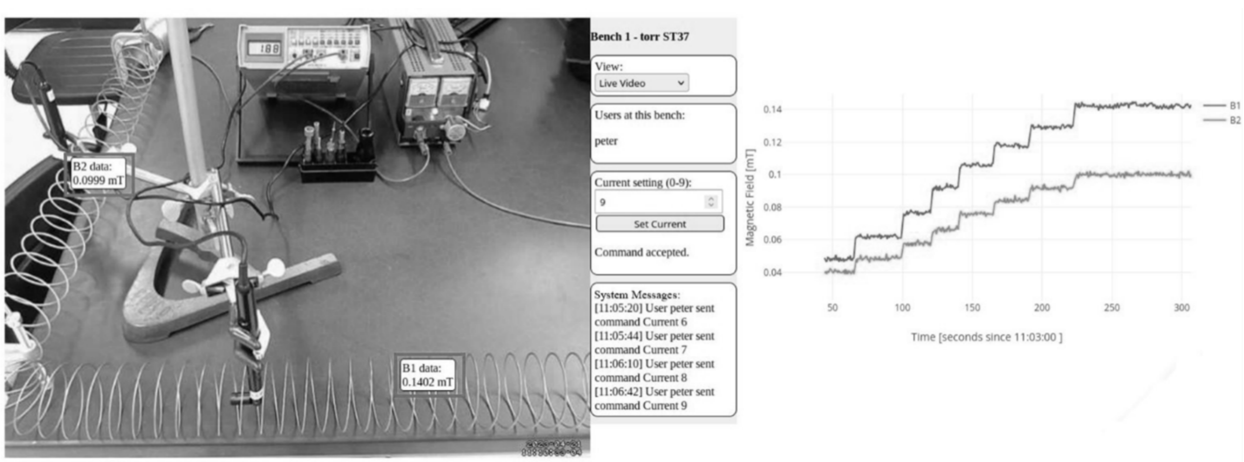
The web interface, shown in Figure 2 and briefly described in the previous section, was a critical part of the solution that needed to be clear and functional for the students to interact with. The center column of the page is where the students could control the remote equipment as well as change what they saw on the page. They could change the view on the left side of the screen by selecting an alternative visual in the "View" drop-down menu. This allowed us to include circuit diagrams and still photos of the equipment to give more clarity to what they were investigating. Anyone at the station could also see all other users logged into the same "bench" to guarantee that they were working with their own group. The next section is where the students could change the settings of the equipment, in this case the current that was travelling through a slinky. The bottom of the center column had a printed history of the commands that were sent to the equipment. This provided the users with instantaneous feedback on who sent what instruction to the operating system so that the group could coordinate the work and plan the experiment in the best way possible. The right part of the webpage was reserved for more data feedback. In the case of experiment depicted in Figure 2, the live magnetic field data coming from magnetic field sensor is presented graphically. In subsequent labs this space on the page was used to show high-resolution photos.

The inclusion of these technical details allowed, not only for secure access to the equipment, protecting both the university network and students' privacy, but also created a steppingstone for the creation of more advanced experiments, ensuring that all course outcomes were met. By the end of the semester four experiments, counterparts to those available to the students during in-person instructions were created, allowing them to develop experimental skills by operating equipment in real-time and collect data that had tangible uncertainties. The design was also very aware of accessibility issues stemming from potential internet speed limitations. To address this, students had the option to view a still image of the equipment or graphical schematic of the setup instead of a livestream, as participation in the virtual laboratory space on Zoom was encouraged.

Additionally, teaching assistants involved in testing the experiments were available online to help troubleshoot and guide students. A member of the technical team was also always present on-site and virtually to provide technical assistance when needed.

Figure 2

A screenshot of the remote lab web interface



Note. Figure 2 shows the screenshot of the lab's web interface. The visual of the experimental set up is shown on the left. The middle section shows the type of the view, users present at the bench, the current settings and the log of actions taken by the users throughout the laboratory period. The right-hand side shows the visual record of the magnetic field values recorded by the sensors.

Evolution and Expansion

Once the first remote lab was competed, it was significantly easier to add more functionality and extend the approach to new and more complicated laboratory experiments. The second experiment was more complicated both conceptually and in terms of precision needed within the experimental setup and data collection. A digital camera was added to the microprocessor controls to allow for high-resolution pictures of a small measuring device (deflected compass needle). A relay switch was also added to provide the ability to toggle between two distinct circuits (straight wire and coiled wire) and investigate the effects they have on the small measuring device.

The next two laboratories were designed for the sole purpose to satisfy needs of the second-year majors' course. The first one, titled "Capacitors and Dielectrics", was written for the remote environment, and required students to collect data needed to determine the value of a known constant by examining the relationship between the capacity of a parallel-plate capacitor and the separation of its plates. The equipment used in this laboratory included an oscilloscope, which records the varying electric potential across the capacitor as a function of time, making the experiment more dynamic than the previous ones. As the measurement is indirect, time-varying, and none of the observed dependencies is linear, both the complexity of the design and the difficulty of the experiment from the pedagogical perspective increased. This experiment saw the addition of a larger stepped motor that allowed the adjustments of the capacitor spacing and repurposing of a cleverly positioned digital cameras to take photos of both the capacitor spacing and oscilloscope waveform. This experiment has since undergone a conversion to the in-person laboratory that keeps all pedagogical aspects of the design.

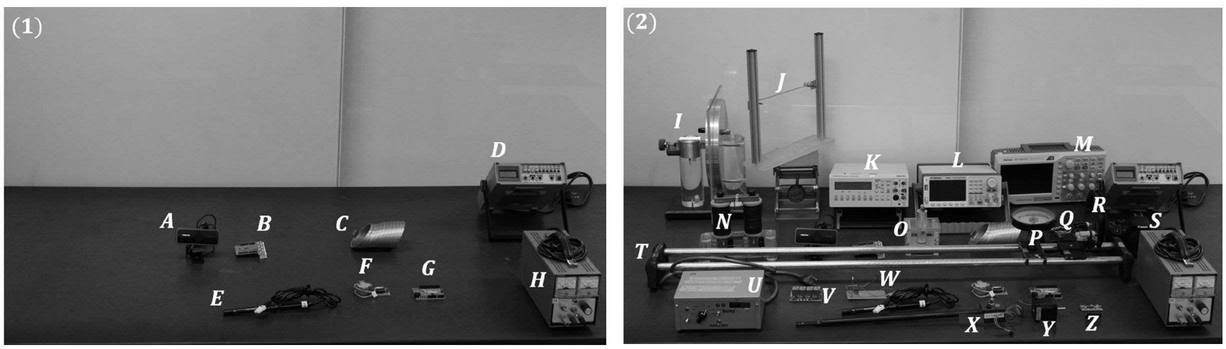
The second experiment, "Hall Effect and Magnetic Hysteresis", which transformed an elaborate experiment previously used in the second-year laboratory course, employed a sensor like those used in the first remote laboratory. This exercise, which requires precision and patience when conducted in person, demanded that students planned and carefully executed the measurement sequence. Because of that, the design needed a more consistent and precise method of adjusting variables. We were able to achieve this using a digital method of variable choice which allowed for controlled changes and rigorous and timely reporting of the readings.

The final laboratory, intended for a modern physics course, allowed for the use of a modified Geiger-Muller counter to measure ionizing radiation over time due to the decay of a radioactive element. While the experiment did not require much engagement from the students in person, as the radioactive samples needed to be handled by a technical staff with appropriate safety training, the non-linear character of the dependence and the nuances of data analysis created a challenging and satisfying laboratory.

Figure 3 allows for visualization of the growth of the laboratories and is a testament to the abilities and potential that the process carries. While this option has not been explored yet, these experiments can now be used to accommodate students who cannot attend in-person laboratories in the future or be employed during remote outreach events and virtual courses, increasing the accessibility and affordability of the learning experiences. Furthermore, this work has opened possibilities for the remote use of equipment and expanded the scope in which microprocessors are used in newly designed laboratories.

Figure 3

Representing the evolution and growth of the remote laboratories



Note. Figure 3 shows: (1) - equipment used for the first experiment (A – web camera, B – Arduino Vernier sensor adaptor, C – slinky, D – digital multimeter, E – magnetic sensor, F – Current/Voltage controller stepper motor, G – Arduino, H – power supply). (2) - all equipment used in the remote labs (I – parallel plate capacitor, J - wire, K – High precision multimeter, L – Function Generator, M – digital oscilloscope, N – electromagnet, O – Geiger-Muller tube, P - compass, Q – Relay switch power bar, R – coiled wire , S – DSLR camera, T – Biot-Savart Law rails, U – Geiger-Muller counter, V – relay switch, W – digital voltage controller circuit, X – Hall probe, Y – large stepper motor, Z - driver for large stepper motor).

Summary and Future Applications

All activities designed during this process were examples of research-informed teaching and a testament to what can be achieved when diverse members of the teaching community bring their strengths together. While originally motivated by the need to create an environment to ensure students achieved experiential learning course outcomes, the remote labs can and are still used today. They are designed to provide accessible learning opportunities when students cannot attend their classes due to extenuated circumstance and can be used to expand the existing outreach program.

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