Teaching Unit Operations Lab in the Pandemic

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Abstract

2020 was a year of many changes. Faculty suddenly needed to convert their courses to an online format. For lecture classes there were many issues to address, but laboratory courses had a special set of concerns. When the lab instructor also left during this year, the author suddenly found herself thrust into teaching unit operations lab. The university was beginning to open up, but there were more students scheduled to be in the lab facilities than the university allowed under the new rules. The author created take-home laboratory kits for several of the experiments to immediately cut in half the number in the lab at any time. The campus plans to be back to "normal" operations in the Fall 2021 semester, but these kits and many lessons learned will continue to make an impact in the classroom. In this paper, the author will discuss the original and future use of these kits and ways that our laboratory courses will continue to function differently.

Keywords

Lab, COVID

Introduction

The 2020-21 academic year was an unusual one in many ways. Concerns about the spread of COVID forced faculty and students off campus, yet the function of the university needed to continue. This new virtual environment worked for some students, but not all. Combine this with the loss of revenue from on-campus students and most universities also faced a serious budget crisis. In many cases, non-tenured faculty were dismissed or, at the least, felt threatened that they would go in the next round of budget cuts. The remaining faculty were stressed by this because they now had more to do in extraordinary circumstances.

Faculty everywhere scrambled to convert their courses to an online format. For lecture classes there were many issues to address, but laboratory courses had a special set of concerns. Initially, faculty ran experiments for their students in front of a video camera and gave the students data from previous years to analyze. In Fall 2020, as the campuses began to re-open for small gatherings of socially distanced students, lab courses at Missouri S&T were allowed to be in person with very small groups. These caps did not accommodate all students in many cases. Thus, other approaches were required. For the Fall, the faculty tried a tight schedule of teams both inside and outside of the designated lab time. Social distancing guidelines were maintained, but the faculty and TAs were overworked. Late that semester, the instructor for the Chemical Engineering Unit Operations (UO) Lab 1 announced that he would be leaving.

The responsibility for taking over the lab was handed over to the author. I had taught the UO lab a few times at another university, so I was not a complete novice. The equipment at my current university was very different and the expectations in the course were very different from before. The course design for our UO lab was intended to be as easy as possible for the instructor, but the student learning had suffered. With social distancing, it also wasn't easy for the instructors or TAs. My solution was to take some of the best elements from my earlier experience and the best of the current plan and re-design the course over winter break.

In the Spring 2021 semester, the UO 1 lab course operated very differently. The UO 2 course was going to continue to operate in the same way (taught by a different instructor). The apparatus for the experiments occupied the same rooms at the same times. With the spacing requirements, we would not be able to all conduct experiments at once. The scheduling plan from the previous semester was not going to work either, because both the TAs and instructors were exhausted. I needed a plan that would allow students to conduct their experiments during the designated lab sessions. The number of students for both UO 1 and UO 2 that were in the lab could be cut dramatically by limiting how many were physically present and the others would be virtually present via laptops or cell phones. For most experiments this was 2 students, a few in UO 2 required 3. As long as the students rotated throughout the semester, everyone would still have significant hands-on experience. This very nearly reduced the numbers to an acceptable level.

The UO 1 course focuses on the equipment that students learn about early in the curriculum such as fluid mechanics and heat transfer and includes some process control. When water flows from your water heater to the shower, you have used concepts from these courses. In the lab the students used industrial style pumps and heat exchangers and tanks. The concepts are the same, however, if smaller, home-sized versions are used. Thus, I created take-home lab kits to replace half of the experiments. The students would still have time in the laboratory to work with the industrial style equipment, but they would have the added benefit of seeing that the concepts work at a variety of scales. At home each team would perform

(1) tank drainage modeling,

(2) measurement of temperature, pressure, and flow, and

(3) creating a pump curve.

The experiments that would be done in the laboratory were

(4) heat exchangers,

(5) open-loop control to characterize a tank drainage system, and

(6) closed-loop control on that tank drainage system.

These were, essentially, a subset of experiments as used in previous years, but the objectives were modified to give more room for student learning. These were scheduled so that all teams performed experiments (1) and (4) in the first third of the semester, experiments (2) and (5) in the second third, and experiments (3) and (6) last.

Lab Kits

Figure 1. Team N performs the Tank Drainage experiment

The tank drainage modeling experiment was new to this course. The students used a tank drainage system in the process control experiments (5) and (6). They developed a model for the system using step tests in (5) and developed a control scheme for the system in (6). The goal for experiment (1) was to develop a theoretical model on a similar system and test it. This experiment was based on a similar experiment done at The University of Tulsa and adapted based on discussions from the AIChE Virtual Community of Practice for laboratory courses. The "tank" was a suspended ketchup dispenser. Water (or another fluid) was gravity drained through a variety of tubes of varying diameter or length. The students needed to create a differential equation model of this and compare their measured values to the theory.

The kit for this experiment included:

- 2-3/16" diameter tank with nozzle top ($0.50)
- A variety of tubes (1/4", 0.17", or 7/64" ID and varied length)
- Bucket ($1)
- Kitchen scale ($15)
- 500-ml graduated cylinder – plastic
- Digital cooking thermometer ($7)
- Garden scaffold ($1)
- Electrical tape, twist ties, and zip ties
- A spare battery for the scale ($0.50)

The tubing and graduated cylinders were acquired from existing supplies. The students signed the lab kit out and were warned that they must return the kit (minus the consumables) in order to earn a grade in the course. All kits were returned in a timely manner.

The students had a poor match between their theory and the data, but this was primarily due to doing a poor job of estimating the losses at the connection. The nozzle top to tube connection was not a smooth transition and the exit tube was not full for the larger tubes. Their models, however, were appropriate for use in experiments (5) and (6) where the connection from tank to tube was more typical. The students were easily able to discern that the hydrostatic head associated with a longer exit tube was much more significant than the frictional losses of that extra length.

The second at-home kit was related to measurement. In the normal laboratory, the students calibrated thermocouples, used a dead-weight gauge to calibrate a pressure gauge, and compared the readings from different styles of flowmeters to physical measurement of that flow in three separate experiments. This could not be replicated at home, but the concept of calibration and direct measurement could be introduced and them we could discuss how and when the laboratory equipment had been calibrated during the on-campus experiments.

The measurement take-home kits used a small submersible pump from the garden center at a local hardware store. These pumps are rated based on the flowrate and maximum height of lift. Since students would be using a homemade manometer to determine the pressure and compare to a Bourdon pressure gauge, a lift of less than 5 feet was good. Most of the pumps were Tetra Statuary Pumps of varying size. The intake is through the vents on the bottom and the flow exits through the opening on the top. The dial on the side adjusts the intake flow rate.

Figure 2. Tetra Statuary Pump (source: www.tetra-fish.com)

Tubing, fittings, and valves were provided so that students could connect the pump exit provided may be set up something like shown in Figure 3. The long exit tube could be raised vertically to deadhead the pump and the vertical distance used as one would a manometer.

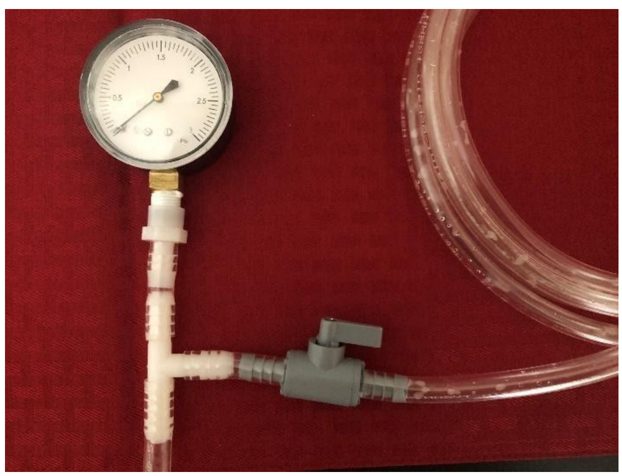

Figure 3: Pressure calibration equipment for the measurement experiment

Students could take a bottle of deionized water from the lab to use for a two-point thermometer calibration using the ice point and boiling point of water. About half the teams chose to use tap water for this calibration.

The flowrate measurement was done with the stopwatch feature of their cell phone and a 500 mL graduated cylinder or scale. Teams were asked to try a variety of techniques to select the most reliable for a future experiment.

Each pump, pressure gauge, and thermometer had an identifying code so that students would use the same equipment (and calibration) on experiment (3). Equipment that was used by more than one team had similar calibration results from all teams, so the quality of the results were acceptable. Students appeared to enjoy this experiment despite (or maybe because of) the frequent water spills.

The final at-home experiment was to create a pump curve for the submersible pump. This was developed based on a discussion of the AIChE Virtual Community of Practice for labs and was unlike the pump performance experiment that students had done in previous years. The at-home student teams received the same equipment they had used in experiment (2), plus an inexpensive power meter. The power meters used were the TKA United Power Meter ($10 on Amazon). The power meter was plugged into an outlet and the pump plugged into the power meter. This power meter operates at 120V, 60 Hz and allows a maximum current of 15 A. The primary mode displays the time connected to a power source in minutes and seconds on the first line, instantaneous power in W on the second line, and current electricity cost on the third line. You can switch to other modes using the FUNCTION button. The display choices are:

Mode 1: Time/Watt/Cost
Mode 2: Time/Cumulative Electrical Quantity
Mode 3: Time/Voltage/Frequency
Mode 4: Time/Current/Power Factor
Mode 5: Time/Minimum Power
Mode 6: Time/Maximum Power
Mode 7: Time/Price

If the display appears to be abnormal or the buttons produce no response, press the RESET button. These were sensitive enough to serve the purpose, but I would not highly recommend them. The students were tasked with measuring as many variables as possible from a typical industrial pump curve for a minimum of five different flow settings. They were given very little additional instructions. The teams developed their own list of variables to be measured, values of those variables, and procedure. Two teams had to perform the experiment a second time because they had not planned adequately on the first pass. Their results demonstrated expected behavior for a centrifugal pump operating far from peak efficiency.

Future Uses of the Lab Kits

For the upcoming school year, the room capacities have been returned to previous levels. The UO lab courses will return to using the equipment in the on-campus laboratory facility. Some students, however, are not ready to return to in-person classes. These kits will be used to minimize the exposure of students who are immuno-compromised or otherwise needing to remain remote. These kits can also be used as a supplement in case of a future breakout of flu or to accommodate distance students. The primary plan for these lab kits is to move them to use for active learning sessions in lecture courses such as our Process Operations course. Instructors may use them for demonstrations or in-class activities. Teams can also check a kit out for homework and projects. Writeups for these smaller activities are in progress.

Permanent Changes to the Course

It appears that operations will be nearly normal for the 2021-22 academic year. The old pump performance experiment will be converted into a pump-curve-creation experiment using the industrial pumps in the lab. The open-ended nature of the experiment appeared to promote greater understanding of pump curves than the previous version of the experiment. The three measurement experiments will continue to be combined as a single experiment, but we will return to using the dead-weight gauge and flow meters from the laboratory. The modeling portion of the tank drainage experiment will be added to the pre-lab portion of the Open-Loop Modeling experiment. This experiment will be replaced by a fluid-flow experiment from previous years.

Another permanent change to the course is that students will be given more flexibility in the operations of the experiments. The old experiments were very formulaic. The students were not intimidated by trying different things with the at-home equipment. In the laboratory, the students have traditionally been told a very specific way of operating the equipment or a specific setting for the equipment. The students talked to each other outside of class comparing what their team found worked best or what happened when they changed a certain setting. The teams needed to use statistical analysis to define “best” and were surprised when they learned that other teams came up with a different answer for that. Although I have no data to support this, I had a distinct sense that they were mentally engaged with the course much more than in previous years. A few even spoke of plans to build small personal projects at their home based on what they had learned.

Conclusion

Social distancing and loss of faculty created a crisis for teaching the unit operations lab courses at Missouri S&T. Some quick changes had to be made, but this has created an opportunity for a more thoughtful re-design of the course. At-home lab kits were one way of adding to the hands-on learning experience of the courses and allowed us to keep all students, faculty, and staff safe. These kits will continue to be used for distance students and in lower-level lecture courses.

References

[1] AIChE Virtual Community of Practice for Labs, https://www.aiche.org/community/sites/divisions-forums/education-division/virtual-community-practice-labs-resources-remote-or-socially-distanced-labs.

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Dr. Christi Patton Luks is a teaching Professor and Associate Chair of the Doshi Department of Chemical and Biochemical Engineering at Missouri University of Science and Technology. She earned her B.S. in ChE at Texas A&M University and a M.S. in Applied Mathematics and Ph.D. in ChE from the University of Tulsa. She is an active member of ASEE having served as Chair of the Midwest Section and Chair of Zone III and currently serving as Chair of Professional Interest Council I and Vice-President of Professional Interest Councils.

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