Teaching Unit Ops Lab in the Time of COVID

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Abstract

COVID forced all classroom teachers to significantly modify their teaching methods and embrace the use of videoconferencing. The teaching of engineering labs was even more challenging and led nationwide to alternatives such as do-at-home labs, lab demos and in-person operation with social distancing. Several modifications were made in the teaching of the unit ops labs in Chemical Engineering at the University of Arkansas to come as close as possible to normal physical lab operation while maintaining safe operation during COVID. These modifications included moving some labs to demos or virtual operation, changes in lab group size, the use of lab videos as preparation for lab and on-line presentations by the students. Student comments on COVID lab operation are presented and the effects of the modifications on the relevant ABET student outcomes are discussed.

Keywords

laboratory, unit operations, chemical engineering, teaching, COVID-19

Introduction

We will all remember the spring of 2020. Most people in the U.S. first heard of COVID on March 6, when a Carnival cruise ship containing 3,500 passengers was not allowed to dock in San Francisco because 21 of the 46 people tested were positive for COVID-19 [1]. By March 11, the World Health Organization had declared COVID-19 a pandemic and, by March 13, President Trump had declared COVID-19 a National Emergency [1]. At the University of Arkansas (U of A), faculty training sessions on the use of Blackboard and Collaborate were offered on March 11 and 12 because the faculty were told that they might need to move to fully remote teaching at some point. Within hours, the Dean of Engineering declared that all faculty needed to be able to teach at least one class remotely by March 19 in preparation for fully remote delivery on a regular basis by March 30. The clear message to the faculty was to “go fully remote and do the best you can to finish out the semester.”

The following summer demonstrated that COVID-19 was here for the long run, but the summer also gave faculty an opportunity to develop expertise in on-line delivery and to plan the content and execution of their classes. Classes in the fall at the U of A were to be taught either remotely (neither students or instructor in the classroom), in-person (instructor and students in the classroom with significantly reduced enrollment) or in a hybrid mode (some students in-person, some students remote, instructor in-person), with a heavy emphasis on a safe working environment for all. This led to most classes being taught remotely or in a hybrid mode. But what about labs?

Undergraduate laboratory courses are generally used to demonstrate the operation of engineering equipment and to generate experimental data to test parameters and validate engineering models. In addition, laboratory experiments are used to develop and improve teamwork and leadership skills and as a vehicle to improve written and oral communication skills. Feisel and Rosa [2] present a history of the development of educational laboratories and how changes have been incorporated throughout the years. Recently, there have been significant developments in the use of virtual labs. Korestky *et al*. [3] note that virtual labs are better for experimental design, critical thinking and dealing with ambiguity, while physical labs are better for understanding lab protocols and specific content. Only physical labs are used in the unit ops courses at the U of A.

The purpose of this paper is to share information on modifications made in the teaching of the unit operation labs used in Chemical Engineering at the U of A for the Fall 2020 and Spring 2021 semesters. The U of A offers CHEG 3233, Chemical Engineering Lab I, which is a junior-level course that mainly covers fluids, and CHEG 4332, Chemical Engineering Lab II, which is a senior-level lab that covers heat transfer, mass transfer and reaction kinetics. Both labs are offered in the Fall and Spring semesters of each school year. Comments on what worked well during COVID operation, what didn't go well and what might be used post-COVID are presented.

What Are Others Doing in the Undergraduate Labs During COVID?

One of the first steps in formulating a plan for teaching the undergraduate labs during COVID was to see what other Chemical Engineering departments were doing. In early April, 2020, Brian Grady [4], the Director of the School of Chemical, Biological and Materials Engineering at the University of Oklahoma, opened an e-mail dialog through the Southeast Chemical Engineering Department Heads on the efficacy of teaching of chemical engineering labs on-line. He was not in favor of entirely on-line labs and suggested that his department may want to "rearrange our schedules so that all fall labs are moved to spring or even summer." Valerie Young [5], the Chair of the Department of Chemical and Biomolecular Engineering at Ohio University, and Regina Murphy [6], Chair of Chemical and Biological Engineering at the University of Wisconsin-Madison, had similar views. Young stated that "we did not design our senior lab to be a 'cookbook' experience," and Murphy noted that "face-to-face instruction, even in non-lab classes, has much to offer versus on-line education, particularly when we are in the business of educating students to adopt new ways of thinking, not just to learn a specific skill." Jeffrey Weimer [7], the Chair of Chemical and Biomolecular Engineering at UC Berkeley, mentioned the use of ultra-low-cost learning modules that were developed at Washington State [8]. Finally, Cliff Henderson [9], the Chair of Chemical & Biomedical Engineering at the University of South Florida, said that they had developed "take-home labs that we use in various courses . . . to give our students hands-on experience in classes throughout our curriculum while they are in things like our intro, thermo, and transport classes."

Additional ideas were presented in a webinar on July 1, entitled "Panel Discussion on Teaching ChemE Labs Online [10]," hosted by Georgia Tech and presented by Stephanie Loveland (Iowa State), Steve Ritchie (Alabama), Yonathan Thio (Georgia Tech) and Laura Ford (Tulsa). Iowa State used on-line labs in Summer 2020 with videos and Zoom calls to explain equipment operation and then provided data to the students for analysis. The University of Tulsa used a number of "do-at-home" experiments, which can be effective in demonstrating basic engineering concepts. The University of Alabama has labs that are instrumented to show output on-line. The labs can be run remotely by the undergraduates by coordinating with the teaching assistant (physically present in the lab), who manipulates the variables in the lab according to instructions given by the students, and then the students can observe the output remotely.

Lab Operation Plans and Execution

After significant discussion, a plan was developed for the unit ops lab for Fall 2020, and this plan was then extended to Spring 2021. Tables 1 and 2 show the operating plans, including the specific labs that were executed, the mode of operation and the required reports and other assignments. Lab I was operated remotely by the instructor due to family health concerns, with two labs carried out virtually (students given data after viewing videos of lab procedures), two labs carried out as demonstrations in the classroom (by in-person TAs and an alternative instructor) and two labs were carried out in-person by the students in the laboratory in the presence of TAs. The in-person labs and demonstrations were conducted with face coverings at all times, and handwashing and cleaning protocols were instituted. The labs selected for in-person delivery were chosen by the instructor as the two best candidates for safe social distancing during lab execution. All report submissions were on Blackboard.

Table 1. CHEG 3233, Lab 1, Assignments and Deliverables, Fall 2020 and Spring 2021

Topic/Lab	Deliverable
Safety training	Safety quiz
Rotameter calibration lab (virtual)	Memo, individual
Impact of a jet (demo)	Fully documented, individual
Draining of a tank lab (lab)	Fully documented, individual
Group presentations, preliminary CATME evaluations	Group oral presentation
Flow meters lab (lab)	Fully documented, individual
Depressurization of a tank lab (demo)	Fully documented, individual
Preparation of pump curves lab (virtual)	Fully documented, individual
Ethics exercise and discussion, CATME evaluations	Ethics paragraph/evaluation
ABET exercise	Quiz

Lab 2 was operated as a hybrid class. All drill (lecture) sessions, including the safety training, were conducted remotely. Lab sessions (four sessions per student) were conducted in person. Students had the option to opt out of in-person classes – in this case the labs consisted of calculations, reports, and presentations based upon experimental data provided by the instructor. Video presentations of the labs were used as training tools for in-person students or as a substitute for the in-person lab experience for the remote students. As with Lab I, the in-person labs were conducted with face coverings at all times, and handwashing and cleaning protocols were instituted. To meet social distancing requirements, lab group sizes were minimized. In addition, the schedule was arranged so that only one lab took place at a time in each of the two rooms used for experimentation – this meant that two labs operated at a time (and reports were due at same time) as opposed to a round robin schedule. For each lab, all preliminary calculations were discussed and submitted via Blackboard.

Table 2. CHEG 4332, Lab 2, Assignments and Deliverables, Fall 2020 and Spring 2021

Topic/Lab	Deliverable
Safety training	Safety quiz
Packed column	Fully documented report*
Shell and Tube Heat exchanger	Fully documented report*
Fin Heat analysis	Fully documented report*
Distillation column operation and simulation	Long form report*, oral presentation

*Individual reports were used in Fall 2020 and group reports were used in Spring 2021

Lab I Activities

After completing mandatory on-line safety training and a safety quiz, the Lab I students ran six laboratory experiments and generated individual reports by each student for each of the experiments. Four of the experiments were designed to compare experimental data with generally accepted correlations. The impact of a jet experiment used an apparatus that was originally purchased from TecQuipment [11] and required the students to compare experimental data with data generated from a force balance. The depressurization of a tank experiment was adapted from the work of Penney and Clausen [12] and the draining of a tank experiment (an original experiment based on the work of Penney and Clausen) also compared experimental data to correlations from the literature and were particularly effective in applying Matlab principles from the department's Computer Methods course. The students calibrated an orifice meter and a venturi meter in the flow meter calibration experiment and determined the coefficients as a function of the Reynolds number. The other two experiments resulted in a simple rotameter calibration curve and a pump curve and gave experimental data that were observed to be quite reasonable with expectations. Figure 1 shows examples of some of the equipment used in the experiments. Each student prepared one memo report (for the rotameter calibration) and five fully documented reports that had a heavy emphasis on detailed procedures, results presented with the aid of tables and figures, a good quantitative discussion and engineering conclusions.

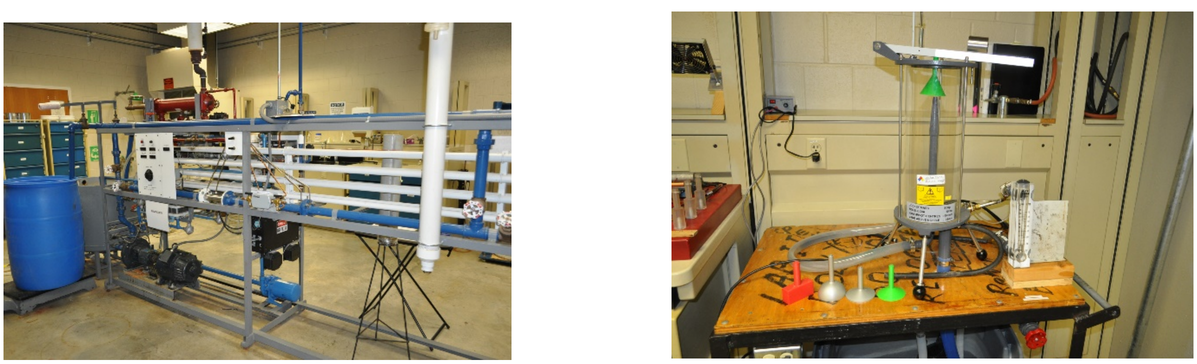

Figure 1. Examples of Lab I Experimental Equipment: flow meter calibration and pump curves (left), impact of a jet (right)

Other Lab 1 activities performed during the semesters included one group oral presentation on a lab experiment selected by the students, peer evaluation using CATME (once for information only and once for information and credit), an ethics exercise and an ABET accreditation exercise. The student group presentations occurred remotely and were presented to student peers and the instructor for questions and evaluation. The groups used PowerPoint and all of the students in each group were required to be equally involved in the presentation. The CATME peer evaluations (one as a practice run at mid-semester and one for credit near the end of the semester) evaluated teamwork, leadership skills and overall ability to function in a group setting. During the ethics exercise, the students were presented with an ethical dilemma from the literature and asked to examine and discuss the dilemma and comment on how they might have handled the situation differently.

Lab 2 Activities

After completing mandatory on-line safety training and a safety quiz, the Lab 2 students ran four laboratory experiments and generated individual (Fall 2020) or group (Spring 2021) reports for each of the experiments. The distillation column experiment consisted of the start-up, operation (with collection of samples for GC analysis) and shutdown of a Xytel pilot distillation column. An Aspen Plus simulation was also performed for comparison to experimental results. The shell and tube heat exchanger experiment included operation of the heat exchanger and simulation with Aspen EDR. The packed column experiment enabled students to operate two small packed beds consisting of Raschig rings and Pall rings. Experimental data were compared with correlations from the literature, and the students also visualized flooding in the columns. The fin heat analysis experiment consisted of collection of experimental data from long rods and comparison to models using MATLAB curve fitting. Figure 2 shows examples of some of the equipment used in the experiments. Each student (Fall 2020) or group (Spring 2021) prepared one long form report (for the distillation column experiment) and three fully documented reports. The long form report is an expanded version of the fully documented report, with extra emphasis on background and introduction of the subject matter. Reports were submitted via Blackboard.

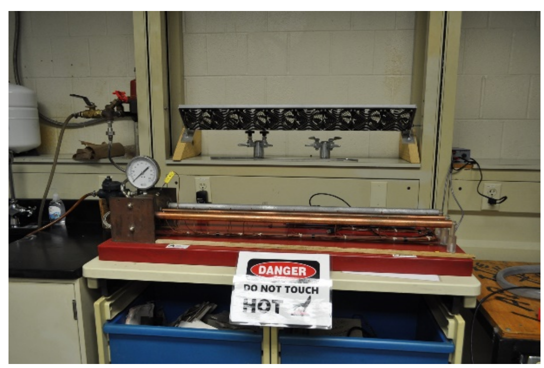

Figure 2. Examples of Lab II Experimental Equipment: Xytel pilot distillation column (left), fin heat analysis experiment (right)

Other Lab 2 activities performed during the semesters included one group oral presentation on the distillation experiment, peer evaluation using CATME (once for each lab, for information and credit), and an ABET accreditation survey. The student group presentations for all students consisted of voice-over PowerPoints, submitted virtually, with no peer evaluation. All students in each group were required to be equally involved in the presentation. The CATME peer evaluations evaluated teamwork, leadership skills and overall ability to function in a group setting.

Lab Videos

Lab videos were prepared by the instructors using Adobe Premiere to assist the students in their understanding of the operation of the equipment, although the videos are generally a poor (but necessary) substitute for hands-on equipment operation without the presence of COVID. The videos for Lab 1 were only 4-8 minutes long, whereas the videos for Lab 2 were as long as 40 minutes and included the entire start-up and shutdown of the equipment. Students were required to view the videos prior to lab execution, an exercise that would likely be beneficial to the students post-COVID as well.

The department purchased iPads to videotape Lab 1 lab demos and in-person lab experiments for students who could not be present in-person. The TAs, students and substitute instructor videotaped the lab exercises for real time viewing or viewing at a later time. This was a great idea, but the video and sound quality were not the best in the hands of amateurs.

Lab Groups

Tables 3 and 4 show the arrangement of lab groups in Lab 1 and Lab 2, respectively, for the Fall 2020 and Spring 2021 semesters. Normal lab groups in Lab I contain 3-4 students, pre-COVID. With COVID, the Lab I groups were intentionally larger to compensate for sick or exposed students missing class. In fact, the lab group containing three students in Fall 2020 had to be combined with another lab group to execute one of the in-person experiments. With six experiments performed, each student was able to serve as group leader. As expected, difficulties were encountered with lab groups of 5-6 students including too little work for all lab members to be involved in executing an experiment and in performing calculations, and not enough presentation time for each group member during oral presentations.

Table 3. Lab Group Set-up in CHEG 3233, Lab 1

Fall 2020			
Section	Students per Group		
001	4	3	4
002	4	4	5
003	6	5	
Spring 2021			
001	5	5	
002	6		
003	4	4	

Normal lab groups in Lab 2 contain 3-5 students, pre-COVID. With COVID, the Lab 2 groups were intentionally <u>smaller</u> to meet social distancing and room capacity requirements. With some groups being as small as two students, the workload was higher per student than in previous semesters. The calculation requirements for most experiments were decreased somewhat to help compensate for this. Physical execution of the experiments was not impacted by having smaller groups.

Table 4. Lab Group Set-up in CHEG 4332, Lab 2

Fall 2020				
Section	Students per Group			
001	4	3	3	2
002	3	3	3	
003(Remote)	3	4	3	3
Spring 2021				
001	4	4	4	4
002	4	4	4	4
003	4		4	4
004(Remote)	4			

Faculty and Student Comments About Lab During COVID

Lab 1

From an instructor viewpoint, Lab 1 went very well, given the constraints forced upon us due to COVID. The students were accepting of the limitations, although everyone felt that lab would have been much better if the constraints were removed. The biggest deficiency of COVID operation was the inability to put student hands on the equipment or even thoroughly understand the operation and limitations of the equipment. This deficiency led to another deficiency in the analysis of results with regard to the limitations with the equipment and the development of sound engineering conclusions.

The students were attentive during the Fall 2020 but grew weary of the COVID ordeal in mid to late spring. Selected comments from the students during the teaching evaluations include:

- I liked that all the course material was uploaded to Blackboard in the beginning of the semester. It was very organized and easy to keep track of since the format never changed. I also thought there was a good balance between in-person and virtual labs.
- Even though this was a hybrid course, I still enjoyed being able to do at least a few of the experiments in person. I do not think this is the most effective way to learn lab as there were times where it was hard to visualize where the data came from when you did not collect it yourself. I am a hands-on and visual learner, and sometimes I struggled with understanding how to utilize the data (thanks to my stellar teammates I did always eventually figure it out). I hope we all get to see each other again in person next semester because I do personally enjoy classes in person far more than online.
- Even though it was all online, I still felt like I understood the labs that were conducted.

Lab 2

As in Lab 1, the biggest deficiency of COVID operation in Lab 2 was the inability of the remote students to put hands on the equipment and understand the operation and limitations of the equipment. Student compliance was excellent with regards to masks, and adequate with regards to social distancing (with frequent reminders). Interactions between instructor and students in the labs were affected by social distancing and masks – communications were sometimes difficult, especially in labs with loud equipment. In addition, there seemed to be a higher level of stress and dissatisfaction in general, independent of any specific difficulties in the class – the overall "COVID experience" seemed to have a negative impact that affected everyone.

Relevant selected comments from the students during the teaching evaluations include:

- Overall, Dr. Smith was extremely helpful and gave timely feedback when responding through email. Although sometimes it was hard to schedule virtual meetings with him for individual help. I do believe Dr. Smith could have done a better job at explaining the labs and lab reports.
- Having lab in-person was incredibly important to me, so thank you for that! Feedback was very helpful for this course. My only recommendation would be to cut the planner tasks. It's much more effective to motivate students to start work earlier by making things due in sections (calculations, MATLAB, etc.) than making tasks. I spent at least an hour making tasks for each assignment and ended up not even following the guidelines I had guesstimated a month earlier. Making things like: equipment list due X/X/XX would have been much more helpful, but I really liked the intention behind this idea.
- Having two lab reports due on the same day is very stressful and did not help me with learning the material. I felt as though I kept going back and forth on each lab report and could not finish either without waiting until the last minute.
- Dr. Smith excelled in communication with the students in this course. I was doing the class from a remote setting and he always made our objectives and due dates clear even going beyond by reminding us when something was upcoming.
- This course needs to be restructured. There is no reason to have two lab reports due within one day of each other. This only leads to procrastination and is not conducive to learning. The lab should be structured like Lab I where you had two or three weeks to complete a lab report. If the real purpose of these labs is to gain experience and learn in-depth about these topics, students don't need to be doing two separate reports at once. I also do not think the MS planner should be required. It should only be a recommendation.
- I think it would be more time effective to make each report due within a few weeks of completing the lab instead of both reports due during the same week.
- Better handouts for some of the labs would go a long way for this course. Also, it is sometimes unclear what the instructor is looking for in certain sections of the report. Having three big projects worth a large percentage of the course grade due the week before finals is not an ideal situation. A suggestion would be to spread due dates out more.

COVID Operation in the Context of ABET Student Outcomes

Four of the seven ABET student outcomes are directly related to the lab courses, although Outcome 1 is largely covered in all engineering courses. How did COVID affect the execution of theses outcomes?

Student Outcome 1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. This student outcome was probably the least affected by course changes made during COVID operation. The calculation portions of the labs were mostly unaltered and were performed in a manner not significantly different from normal operations. The only issue was assembling the groups safely to work on calculations.

Student Outcome 3. An ability to communicate effectively with a range of audiences. Written reports were not affected, but the conversion from in-person presentations to virtual presentations was a major difference. Lab 1 students performed virtual group presentations in place of typical in-person presentations and were still able to address peer and instructor groups. Students lost some development of in-person presentation skills but gained experience with virtual presentations. The decision to perform presentations as voice-over PowerPoints in Lab 2 helped develop that one particular skill but lacked development of either virtual presentation skills or the typical in-person presentation skills. Both labs missed out on an opportunity to broaden the types of audiences for the presentation – the virtual environment could make this an easier task to accomplish. Audiences consisting of chemical engineering alumni and the general public could perhaps attend virtual presentations more easily than the typical in-person presentations.

Student Outcome 5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. Team interactions are still critically important in the remote environment. Some team planning activities (such as use of MS Planner for experiments) were increased, with mixed feedback from students. Lack of in-person student interaction had a negative impact on team effectiveness, especially with communication between team members. More proactive team development and monitoring activities should be implemented in this environment.

Student Outcome 6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. We believe that there is no adequate replacement for in-person lab experiments. The ability to conduct appropriate experimentation was negatively affected for students that attended remotely. The remote students also had more difficulty with the ability to interpret data and use engineering judgment, seemingly to lack some understanding gained from the hands-on experience. For those students, the experiments seemed more abstract. The students did not fully comprehend concepts such as potential sources of error and disagreements between theory and experimental results.

Information for Post-COVID Operations

We made it through two semesters of COVID. But were there practices that were used during COVID that could be useful during post-COVID operation? Here are a few possibilities:

- The lab videos were a good idea and could easily be used to enhance student preparation prior to the labs. Perhaps the best way to handle this might be to require the students to view the video of the experimental procedures and then visit the lab with the instructor or TA prior to experimentation to maximize student preparation.
- The extensive use of Blackboard during COVID to post all assignments and background information, collect reports from the students and to show graded reposts and other grades should be continued post-COVID.

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