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Teamwork Development and Evaluation for Hybrid Thermal Fluids Laboratory Course

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Abstract

Laboratory courses provide an opportunity for students to practice engineering skills in ways not possible in a traditional classroom environment. Hands-on activities challenge their creativity, problem-solving, and critical thinking. Beyond that, labs are an ideal platform for developing teamwork and communication. In normal circumstances, providing quality lab experiences can be resource intensive and logistically challenging, particularly for large class sizes. This year, new safety measures required by Covid-19 have completely changed the equation, adding constraints few of us could have anticipated a year ago. One solution to the Covid-19 puzzle is remote learning; this might involve video demonstration of experiments, simulations, and/or 'at home' experiments. Another option is to continue to offer in-person labs with added safety measures to include mask wearing, social distancing, and enhanced cleaning. For the Fall 2020 thermal-fluids laboratory course at the University of Virginia (UVA), a hybrid model was adopted. Students were given the option to take the class 100% remotely, or they could attend lab in person every other week. During the second week of the semester, entire sections met online for team forming. Though some attempt was made to group in-person students in the same team, several teams had a mix of in-person and remote students. The curriculum was redesigned into two-week blocks. During the 'on' week, students collected data from an experiment they performed in person or watched virtually. During the 'off' week, they worked in teams on various activities including report peer review workshops, a team project, and post-processing of the previous week's experiments. This paper will discuss how the course design fostered team development in the hybrid learning environment. Metrics from each mode of delivery: in-person and remote, are assessed. These will include performance on individual and team assignments, and team member peer evaluations via Comprehensive Assessment of Team Member Effectiveness (CATME) evaluations.

Introduction

Lab experiences are an essential part of any engineering curriculum. Expected outcomes for these experiences are clearly communicated through ABET Crtierion 3, Outcome 6, which states that program graduates should have "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.[1]." Beyond skill in experimentation, however, laboratory courses are often ideal for developing proficiency in technical communication and teamwork (ABET Outcomes 3 and 5)[1].

Thermal Fluids Laboratory is the second course in a redesigned 3-course experimental lab sequence for Mechanical and Aerospace engineering students at UVA. Each course is 2 credit hours and includes 50 minutes of lecture and 2 hours of lab per week. The sequence was designed to expand the amount of 'hands-on' experience within the curriculum and to horizontally align lab experiences with required courses in mechanics and thermal sciences. Faculty teaching foundational courses identified a need for students to have tangible activities demonstrating the concepts they were learning, which is achieved with targeted alignment of the lab courses. At the same time, the three courses are scaffolded so that students' build experimentation, communication, and teamwork skills over three semesters. In particular, Thermal Fluids Lab is aligned in the same semester students take Fluid Mechanics, a semester after they have had Thermodynamics, and a term before they take Heat and Mass Transfer. It incorporates a significant individual writing assignment and final team project, in addition to a number of focused experiments with team-based assignments.

The first offering of Thermal Fluids Laboratory was delivered, as it was originally conceived, in Fall 2019. Students attended in-person lectures, worked in teams in-person during the lab period, reviewed peer written work during in-person lab time, provided face-to-face feedback for team project proposals, etc. A global pandemic made this model impossible to repeat for Fall 2020. This paper outlines how this laboratory course was adapted to comply with university policies dictated in response to Covid-19. The following section sets up the course design as an engineering problem including constraints set by curricular requirements, university policy, and physical resources; and pedagogical outcomes established as objectives. Details of the 'solution,' a hybrid course with a remote option, are provided and defended with respect to these constraints and objectives. The effect on development of teamwork is then addressed specifically, including differences between remote and in-person students. This is followed by an overview of the experiments involved and how these activities were managed between both in person and remote students. Metrics from each type of team are assessed to include performance on individual and team assignments and peer evaluations. Finally, the paper summarizes lessons learned and makes some recommendations applicable to lab courses in general.

Engineering a Hybrid Model as Solution to Pandemic

Prior to bringing students back for Fall 2021, the university issued guidance to faculty that included two principles: (1) deliver the mission and (2) take necessary measures to promote the health and safety of all concerned [2]. This meant proceeding with plans to deliver the Thermal Fluids course to 131 third year Mechanical and Aerospace Engineering students as a required part of their curriculum while making modifications necessary to do this safely in the midst of a pandemic. In keeping with the first principle, there would be no change in the course learning objectives, which cover three ABET outcomes [1], in short: experimentation (#6), teamwork (#5), and an ability to communicate (#3). In addition, activities were to be designed for students to put into practice theoretical concepts in thermodynamics and fluid mechanics, progressing from knowledge-based learning to application. However, two major restrictions meant that accomplishing these outcomes would look different than in previous years. For one, in person classes had to keep students socially distanced. This significantly reduced the capacities of all classroom and lab spaces, typically to 1/3 or less of the original capacity. It also meant the traditional approach of having teams work together at a single lab station would not be permitted. Another major requirement was to have a remote option for any student that wanted it. Other measures such as a mask mandate and prolific Covid-19 testing were vital to meeting the second guiding principle, but had less of an impact on course design. In addition to firm restrictions and requirements, there were a few strong recommendations from school administrators influenced by a desire for equity within the classroom. For one, the content should be 'equivalent' for all students; in other words, remote students should not be disadvantaged. We were also encouraged to make asynchronous options available to the extent possible, to accommodate students who may be in different time zones or have daytime commitments at home.

With the problem defined above, the next step was to take an assessment of resources that could be made available. Assets for in-person instruction include a dedicated Thermal-Fluids Lab room, additional rooms in the same building, lab equipment, lab computers with suite of engineering software, and preexisting content from the 2019 course. The Thermal-Fluids lab room has seven experiment stations designed for teams of 3-4 students each when <u>not</u> socially distanced. Lab equipment includes hydraulic bench experiments from TeqQuipment, PASCO sensors and apparatus, National Instruments data acquisition modules, and custom equipment built in-house. The 2019 course design included eleven modules with pre- and post-lab assignments. Assets for remote instruction included the learning management system (Sakai-based), professional licenses for Zoom for all faculty and students, and student licenses for certain software packages (SolidWorks & Matlab). Two options were also considered to get resources to remote students: (1) having them purchase equipment or (2) shipping equipment to students.

Given these constraints an resources, only two delivery options were feasible: (1) a 100% remote course or (2) a hybrid course (some remote and some in person) with a fully remote option. The advantages of a 100% remote course is that it would enable a uniform experience for all students according to a single standard schedule. Despite this advantage, several factors drove the decision to choose a hybrid model. First, by late summer it was clear that a majority of students (about 70%) would return to campus. Nonetheless, given the size of most engineering courses and the reduced capacity of the classrooms, it was also clear most of their classes would be online. Finally, the added value of attending a lab in person would be worthwhile. In fact, for most of this cohort, Thermal Fluids lab was their only in person or hybrid class for Fall 2021.

With a hybrid concept selected, the next step was to work out logistical details. The 131 student cohort had been divided into seven sections of no more than 22 students each, with lab times designated Tuesday, Wednesday, and Thursday afternoon and evenings. Each and every section had a remote option, meaning there was no formal distinction between students taking the course remotely vs. in person. In fact, as the semester started, it was clear that in-person students might need to switch to remote learning if required to quarantine or isolate due to exposure to the Covid-19. A total of 11 lab stations were set up including 7 in the Thermal Fluids Lab and 4 new stations in a second room on the same floor. This allowed half of the students in a section to be in lab simultaneously. Thus, the students were divided into A and B groups and put on an alternating lab schedule. During the 'on' week, students completed experiments in person if possible. Videos of a teaching assistant completing the lab procedure were provided for those who were not able to come in person, from which the students had to acquire data for themselves; more details on how this worked are provided in the "Other Experiments & Activities" section of this paper. During the 'off' week, students worked remotely within their teams to complete post-processing of the previous weeks' labs and to work on a semester-long writing assignment with peer review. Teaching assistants were assigned a primary section for which they supervised in-person work and a secondary section for which they were available for remote students. Book ending this rotation schedule were 3 weeks of online only-instruction to start the semester and two weeks for project work and presentations at the end of the semester. An asynchronous concept lecture accompanied each lab activity, and a synchronous online question and answer session was hosted on Monday afternoons.

Assessment was based on six categories. Prelab assignments, worth 10%, were individual homework-style assignments completed through the learning management system (LMS). They are based on information obtained from the laboratory handouts and supplemental background documents. Post-lab assignments, worth 30%, require lab teams to synthesize, document, and analyze results from tests and experiments. A semester-long writing assignment, worth 20% incorporated a lab report and double-blind peer review. There was also a team designed project and virtual poster presentation, worth 15% and a final exam, worth 20%. The final category, "Teamwork and Professionalism," worth 5%, included participation in team building activities as well as feedback from and to teammates. The next section provides further details on how team skills were developed within the course.

Team Forming

Teamwork is an integral part of the lab structure, and perhaps the aspect most 'at risk' with the hybrid/remote option model. As typical with all the lab courses, teams of 3-4 students were assigned for the duration of the semester using the CATME (Comprehensive Assessment of Team Member Effectiveness[3]) team builder survey. A custom question was added to the survey to determine which students needed the 100% remote option (38 of the 131 students selected this). The CATME Team Builder tool allows instructors to dictate preferences to apply to the built-in team selection algorithm. In this case, priority was given to group teams based on delivery mode (i.e. in person or remote). The rationale here is that remote students would have an easier time working among themselves rather than trying to integrate with teammates that had the advantage of seeing each other in person. However, there were a few sections for which teams had to be mixed (2 in-person students and 2 remote only students) due to the demographics of the section. In-person teams were also asked to adapt if and when teammates were required to go remote mid-semester in order to isolate or quarantine. The first three weeks of the course were conducted online for all students. This allowed time to set up expectations during week 1 and work through a team forming exercise in week 2.

Immediately after learning of team assignments during the week 2 lab session, students played *Icebreaker Bingo*. Bingo is a common icebreaker tool [4], where participants roam around a room, seeking out others with particular attributes that allow the player to claim boxes on a 5x5 bingo grid in order to make "Bingo" by claiming a full row, column, or diagonal of boxes. A few significant tweaks were implemented to make this feasible online. First, a single Bingo grid is used for the entire class. The grid starts off empty except for one box filled by the instructor with a personal attribute, e.g. "I've hiked part of the Appalachian Trial" or "I've visited Mexico in the past 2 years." Then, teams are sent to breakout rooms with their new teammates to discover attributes they have in common with each other. Upon returning from team breakout sessions, the game begins with teams claiming the instructor box if any member shares the attribute listed. In Zoom, this is done by adding a team-specific annotation stamp to the box. Then, teams are selected in random order to fill in any open box with an attribute their team members share; other teams are allowed to claim the same box if any of their members share the attribute. The first team to claim Bingo wins bragging rights. From the prior lab course, students in the cohort had participated in an activity based on the team policies and student expectations assignment presented by Oakley et. al.[5]. Rather than repeat this activity exactly, teams were sent to breakout rooms a second time to discuss an ethics case study and to develop a Team Compact agreement outlining expectations they have for one another.

After the second week, teams worked together to complete post laboratory assignments, to provide a blind peer review of lab reports from other students, and to complete an end of semester project. For the most part, teams met during the ‘off’ lab week to accomplish these tasks. A teaching assistant was available in a course Zoom session to answer questions, but teams were given the freedom to meet on their own schedule using their own Zoom sessions. In hindsight, this flexible attendance policy may not have been the best for many teams. Based on post-course student feedback, a few online only teams would have benefited from more oversight to ensure the entire team was engaged. Each student completed a mid-semester peer survey and a final evaluation of their teammates.

Emphasis on Technical Communication

Technical communication is an important element of all three experimental lab courses. In the Thermal Fluids Lab, students are required to write a full laboratory report. This individual assignment is accompanied by substantial instruction on report standards, followed by a two-stage blind peer review. For this assignment, all students were tasked with completing a calorimetry experiment remotely during the 3rd week of class, before the ‘on’ and ‘off’ week rotation began. Since this was such a critical element in the course, it was particularly important that both hybrid and remote students were working under the same constraints. All students were asked to purchase a pocket scale and a digital thermometer. For this experiment, they also needed an insulated cup, a means to heat or cool water above or below room temperature, and metal objects (pennies or other coins were recommended). They were given autonomy to establish an appropriate procedure to test the specific heat capacity of the objects. The purpose of the experiment was two-fold. First, it provided a review of closed system analysis from Thermodynamics. Second, by designing the experiment themselves, the students own all aspects from cradle (experiment design) to grave (reporting of the results through the laboratory report). Instruction and implementation of the blind peer review follows closely the process described in an earlier paper [6].

In addition to the lab report, students worked within their teams on an end of semester project. The project could be an experiment or a device design, either of which could be physical or virtual. Teams presented ideas for their project during one of the ‘off’ week Zoom sessions to get feedback from their peers. During the last lab period of the semester, all teams presented their projects in a virtual poster session. During the session, each team was given a Zoom breakout room for their virtual poster. Each team member presented the team’s work in 3 consecutive ten-minute sessions during which the instructor, teaching assistants, and non-presenting students from other teams rotated through to listen and ask questions. By the end of the two hour lab period, all four team members would present. To encourage an engaged audience, students were given a short assignment based on what they learned from their classmates' projects.

Other Experiments & Activities

A list of the lab modules are shown in Table 1. Beginning in week 4, in person students began to rotate through in person labs every other week. Remote students completed the same lab experiments. In a few limited cases, like the Density and Buoyancy lab, remote students could perform the work at home using limited equipment such as a graduated cylinder, pocket scale, household fluids, and miscellaneous objects that float or sink. In most cases, however, a video recording was provided of the teaching assistant or instructor performing each experiment. Still photos were embedded within the videos for measurement events. Remote students watched the videos to make their own observations and to take data. These videos had little to no audio but some captioning to explain what was happening. The intent was for remote students to observe the procedure and be responsible for taking data in the same way in-person students would. An example of a measurement photo embedded within one of the videos is including in Fig. 1. Note that students must observe the position of the jockey weight needed to determine the measured jet force and read flow rate from the hydraulic bench in the correct units. These stills come in the video after the students observe the procedure for adjusting the flow and balancing the jockey weight. Figs. 2 and 3 show similar embedded photos for the Flow Measurement lab. Teams worked together to process experiment data and complete a single post-lab assignment. In person and mixed teams often had multiple sets of data due to completing the experiments individually; they were encouraged to include all data taken in the post lab, but were only required to have one complete set.

Table 1: Thermal Fluids Lab Experiment Modules

Team Forming Exercise. Teams develop policies and expectations.
Closed System Experiment and Report. Verify specific heat capacity of metal object. Performed remotely by all students. Followed by guided lab report with peer review.
Density and Buoyancy. In person or remote experiments exploring direct and indirect ways to measure density, and Archimedes principle.
Impact of Jet. Test conservation of linear momentum for a jet of water impacting a vane.
Viscosity. Measure viscosity from a sphere drop test.
Flow Measurement. Take measurements using a Venturi, orifice meter, and rotameter.
Team Project. Design and execute experiment or build device based on principle of thermodynamics or fluid mechanics.

The number of experiments was intentionally reduced from Fall 2019, when all instruction was in-person. From both the instructor and student perspective, most activities require significantly more effort in an online environment. In addition, a minimum of 2 weeks were needed to rotate groups through the 'on' and 'off' week schedule. The university calendar was also altered to end all instruction by Thanksgiving. In addition, a few 2019 modules, focused on data acquisition from temperature and pressure sensors, were not practical for either an online or socially-distanced in-person lab. Using National Instrument's LabView and PASCO Capstone software were ruled out since those licenses were only available on department owned computers. To compensate for less time in the lab, several video recordings were provided to present conceptual material needed to understand the lab activities and on expectations for the lab report. These were made with the aide of a Wacom One tablet so that 'notes' were handwritten in real time in a manner similar to notes on whiteboard. The intent of this was to encourage students to take their own notes. Video lectures were complemented with weekly question and answer sessions.

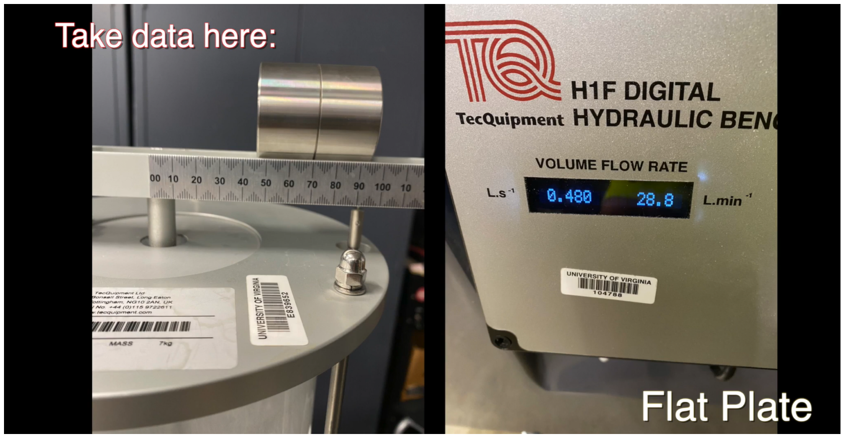

Figure 1: Example video insert from Jet Impact Lab.

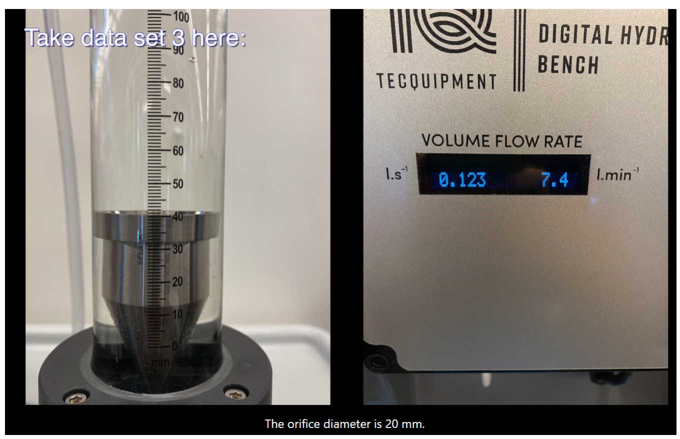

Figure 2: Example video insert showing rotameter position from Flow Measurement Lab.

Assessment & Recommendations

Due to the unexpected and challenging circumstances brought on by the pandemic, expectations for the semester were appropriately modest. Accordingly, three questions were the focus of course assessment: (1) were students able to successfully complete the course? (2) in doing so, did they achieve the learning outcomes? and (3) did remote only students have an equal opportunity for success? One concerning metric concerning the first question was the number of students who enrolled in the course. The total enrollment (131) was higher than normal due to an unusually large class, but it also represents a drop of about 7% from the prerequisite lab course in Spring 2020. Traditionally, the Fall Thermal Fluids course has higher enrollment (10% higher in 201) than the Spring Mechanics Lab course due to an influx of 10-20 transfer students. On a positive note, 99%

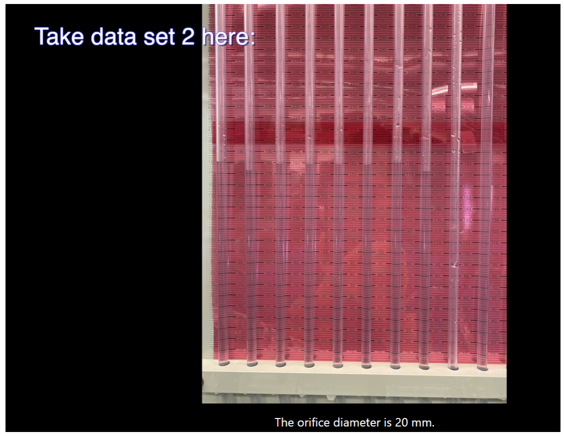

Figure 3: Example video insert showing manometer readings to determine pressure drops across a Venturi and Orifice meter from Flow Measurement Lab.

of students who enrolled passed the course, in keeping with the general trend for the experimental lab courses within the department. In terms of the course outcomes, student performance on the final lab report submission and the end of semester team project were assessed. The average score for the lab report was 81.0% and 91% of students achieved a 70% mark or better. The project presentations were excellent, with 100% of students earning at least a 70%. Also of particular note regarding the project is that participation in the virtual poster presentations was 100% despite being held the last week of class. The lab report provides evidence for both the experimentation and communication outcomes. The project presentation supports both technical communication and teamwork outcomes. In addition to student performance, a final CATME peer survey reflected high satisfaction among teams. Statements such as "I am satisfied with my present teammates," "I am pleased with the way my teammates and I work together," and "I am very satisfied with working in this team" all resulted in averages in the 4.4-4.6 range on five point Likert scale with 5 being 'strongly agree.'

One major concern going into the semester was how to deliver an 'equivalent' experience for both online and remote students. Admittedly, with students on two different schedules, it was difficult to give the fully remote students the same level of attention as the in-person students during normal lab hours. However, holding evening office hours was helpful in ensuring all students had access to the instructor as needed. After the course was completed, t-tests were conducted on a few particular metrics to determine if the remote students performed differently than in-person students. These included the overall course grade, the final exam grade, the team project, and the lab report. P-values for these metrics were 0.206, 0.656, 0.222, and 0.0663. Interestingly, the remote students actually had higher average grades on all but the final exam where the difference (P-value of 0.656) was the least significant. Similarly, a t-test was conducted for teammate peer evaluation scores and no significant difference was found between remote only and in person teams (P-value of 0.88). It should be noted that the sample sizes were different but that variances were comparable.

Lessons learned from this experience can be applied to future course offerings, though hopefully under better circumstances. First, efforts to establish routine even with complex schedule are helpful for students, teaching assistants, and students. Thermal-Fluids benefited from a regular schedule during the middle of the term with the ‘on’ week, ‘off’ week rotation. As this changed toward the end of the semester, students expressed more confusion about attendance requirements and due dates. On a similar note, even small efforts to establish a predictable pattern can pay off. Teams were assigned a color as a team name, and those are repeated in each section. This helped establish a consistent schedule among all sections, e.g. ‘teams Red, Orange, and Yellow are in-person this week.’ Detailed information on the LMS, provided in a predictable location was critical to keep everyone apprised of what was going on from week to week. One missed opportunity from the Thermal Fluids lab was to encourage remote students to meet in a common Zoom session, with breakout rooms established by the secondary teaching assistant; this would have provided opportunities to check-in periodically and would likely have helped to engage a few students who might not appreciate the value of working together at the same time, in the same virtual place. A final regret is not having some more engaging remote activities, such as flow simulation exercises or activities that require programming.

Conclusions

The Thermal Fluids laboratory course has ambitious outcomes, from teaching experimentation principles to developing soft skills in teamwork and communication, to providing tactile examples of concepts in fluid mechanics and the thermal sciences. At the same time, students value lab courses for the ‘hand-on’ experience it delivers as well as the opportunity to work with their peers in creative problem solving. Thus, it was important to offer some in-person lab experiences for Fall 2020, despite severe restrictions imposed by the university to respond to Covid-19. These restrictions included reduced capacity of the lab spaces as well as a requirement than students be given a remote only option. This paper discussed the hybrid/remote-option model used to deliver Thermal-Fluids Laboratory at UVA. The logistics were challenging requiring two different course schedules that brought students in on alternate weeks and creation of content for remote students to complete equivalent assignments. In the end, despite a reduction in the number of activities and a small drop in enrollment, students were able to achieve the desired outcomes. This included remote only students who performed just as well, and in some cases better, than those following a hybrid in-person schedule.

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