Paper ID #35691

From Social Distancing to Enhanced Learning in the Laboratory

Dr. Alison Rose Kennicutt, York College of Pennsylvania

Alison is an Assistant Professor of Civil Engineering at York College of Pennsylvania. She received her B.S. in Civil Engineering and her M. Eng. and Ph.D. in Environmental Engineering from Rensselaer Polytechnic Institute in Troy, NY. Her research interests are in drinking water treatment of emerging contaminants and the production of disinfection byproducts. At York College, Alison loves to use hands-on exploration, both in the field and the lab, to trigger curiosity and get students excited about engineering!

©American Society for Engineering Education, 2021

From Social Distancing to Enhanced Learning in the Laboratory

Abstract

The COVID-19 pandemic posed a particular challenge for laboratory-based learning. As many institutions returned to in-person learning, social distancing (via reduced capacity) was established within classroom spaces. Following these guidelines, our environmental engineering laboratory space could only accommodate one-third of the registered students in each of the Spring 2021 lab sections. To overcome this, I created a weekly rotational schedule of in-person, virtual, and field/home activities. This rotational schedule resulted in smaller groups of students for the in-person labs and increased my ability to assess individual student progress toward specific learning objectives. Students indicated this allowed them to work more independently on experiments, improved skill development and retention, and ultimately created a more personal learning environment. As we return to our "new normal," we should deliberately and critically evaluate whether our pandemic-induced innovations created an enhanced learning environment, when compared to traditional course delivery.

Background

The COVID-19 pandemic will undoubtedly remain an infamous landmark in the world of higher education. While every area of education was impacted, overcoming the challenges of reduced capacity, remote learning, etc. was a particular challenge in laboratory settings. Similar to many others, our institution's return to campus included a "HyFlex" modality for the Fall 2020 and Spring 2021 semesters, where students would rotate through in-person and remote learning (i.e., via Zoom) for individual courses and/or lessons. The HyFlex schedule was set by the individual faculty member, depending on course enrollment and the limitations on classroom capacity, as set by social distancing guidelines. There was also a small subset of our student body who were approved (e.g., due to medical exemptions) to be fully-remote for the semester and exclusively participated in synchronous sessions via Zoom.

York College of Pennsylvania (York, PA) is a private, medium-sized liberal arts college with a four-year Civil Engineering program that includes three full-time semesters of co-operative (co-op) experiences. Civil Engineering is the newest engineering program at York College, having graduated its first cohort in August 2020. Our sophomore-level Introduction to Environmental Engineering course is run as a three-credit lecture (three 50-minute sessions per week) with a one-credit lab (one 165-minute session per week). For a pre-pandemic semester, lab sections have been typically capped at 16 students; to accommodate the Spring 2021 cohort enrollment (33 students), lab sections were capped at 12 students to ensure a relatively even distribution of students across the sections. Following social distancing guidelines, our environmental engineering laboratory space could only accommodate one-third of the registered students in each of the Spring 2021 lab sections.

In previous semesters, the lab sessions had been used to conduct physical experiments, to explore data analysis techniques, to introduce stand-alone topics (e.g., risk assessment), and occasionally as an exam period. Each week would consist of a single activity for all students and all activities were conducted synchronously. My primary goal was to maintain the integrity of the laboratory portion of this course and give as much hands-on content as possible, without sacrificing any individual's experience or relegating a group of students into a "Zoom observation space" for a given activity. For students who were fully-remote for the semester, equipment limitations unfortunately made this unavoidable at times, but this was minimized as much as possible in the planning and structure of in-person lab work.

I implemented a rotational schedule (**Figure 1**) that allowed strategic placement of in-person activities ("in lab" or "in classroom"), that would take place in the limited laboratory space, in conjunction with supplemental activities that could be conducted independently and/or asynchronously by students virtually ("virtual") or in the field ("in field").

	Lab Group A	Lab Group B	Lab Group C
Week 1	NO LABS THIS WEEK		
LAB SET I			
Week 2	Policies and Regulations (Video) VIRTUAL	Policies and Regulations (Video) VIRTUAL	Lab Safety Training and Measurements of Mass & Volume IN LAB
Week 3	Policies and Regulations (Discussion) VIRTUAL	Lab Safety Training and Measurements of Mass & Volume IN LAB	Policies and Regulations (Video) VIRTUAL
Week 4	Lab Safety Training and Measurements of Mass & Volume IN LAB	Policies and Regulations (Discussion) VIRTUAL	Policies and Regulations (Discussion) VIRTUAL
LAB SET II			
Week 5	Making Calibration Curves VIRTUAL	Water Quality Kits IN FIELD	Measuring pH and Conductivity IN LAB
Week 6	NO LABS THIS WEEK		
Week 7	EXAM 1		
Week 8	Water Quality Kits IN FIELD	Measuring pH and Conductivity IN LAB	Making Calibration Curves VIRTUAL
Week 9	Measuring pH and Conductivity IN LAB	Making Calibration Curves VIRTUAL	Water Quality Kits IN FIELD
LAB SET III			
Week 10	Dissolution-Precipitation IN CLASSROOM → IN LAB	Oxygen Demand VIRTUAL	Turbidity + Stream Sampling IN LAB → IN FIELD
Week 11	EXAM 2		
Week 12	Oxygen Demand VIRTUAL	Turbidity + Stream Sampling IN LAB → IN FIELD	Dissolution-Precipitation IN CLASSROOM → IN LAB
Week 13	Turbidity + Stream Sampling IN LAB → IN FIELD	Dissolution-Precipitation IN CLASSROOM → IN LAB	Oxygen Demand VIRTUAL
Week 14	Virtual Tour of York Water VIA ZOOM		

Figure 1 *- Rotational schedule of laboratory activities for students divided into designated groups A, B, and C, within each lab section.*

Students in a given section were subset into three groups (A, B, and C) and rotating lab activities were similarly grouped into sets (I, II, and III). Student groups were randomly assigned prior to the start of the semester and remained the same for the duration, primarily to provide consistent and predictable scheduling for students. Lab sets contained three rotational activities and occasionally a ubiquitous activity (e.g., an exam or virtual field trip). From the instructor perspective, the active teaching time each week did not change when compared to a pre-pandemic semester. While I was still actively (in-person) instructing three hours per week for each lab section, the alteration was that I would teach the same activity for three weeks in a row, with a different subset of students for each iteration.

Consideration for Permanent Implementation

From the instructor perspective, the intimate learning environment created by the rotational schedule introduced a much more enjoyable teaching experience. Using small groups or small lesson sizes is an established technique to enhance active learning [1]–[4]. It was easier to connect with students individually and to engage them in the lab content. Students who seemed to be quieter and more reserved during the larger lectures were more apt to respond to questions and to volunteer their own. There was flexibility to find a piqued interest and follow that tangent, which often allowed the students to see my own excitement about the work and in turn, created some of their own. I have had more students inquire about independent study and research opportunities after this semester than any other prior.

Students also responded favorably to the alternative structure of lab sessions. At the end of the semester, students were anonymously surveyed for general feedback on the course. Responses pertaining to the laboratory portion of the course were evaluated on a five-point Likert scale, ranging from "never" (one) to "always" (five) (**Figure 2**). Eighty-seven percent of students found the smaller in-person lab groups to be at least "usually" enjoyable and 88% of students found the more intimate setting to be at least "usually" beneficial to their learning. Thirteen out of the 32 students who submitted the survey also submitted positive feedback in the open-ended comments portion of the survey. One student elaborated that "the small lab groups were nice and made it a lot better to get one-on-one attention, ultimately improving learning." Another commented "it felt that we had a lot of attention on us and we were allowed to learn stuff better, rather than other people doing the actual lab and then you watching."

Even though the implementation of this rotational, small-group system was formed as a relatively urgent response for teaching during the COVID-19 pandemic, its success can be attributed to a few key considerations during its design and implementation: consciously evaluating how the lab activities coincide with each other and the lecture topics, finding opportunities for a virtual format to be an enhancement instead of a compromise, using an intimate setting to remove some structure and allow more exploration, design opportunities for individual skills-building and recall, and shifting the mode of assessment and follow-up to target these varying types of learning objectives. These considerations are highlighted in the following sections, using specific examples pertaining to this environmental engineering course, but could easily be applied to other engineering laboratory experiences for the entirety of a semester or even a portion of the lab sessions.

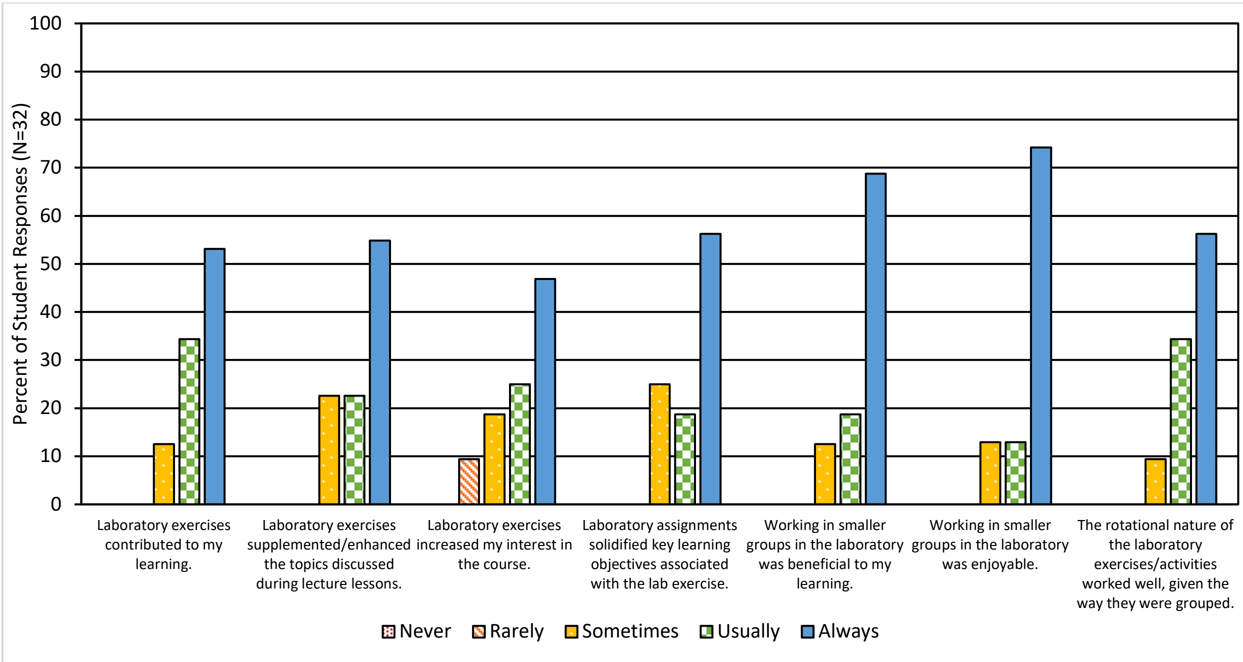

Figure 2 *– Summary of student responses to end-of-semester survey questions pertaining to the laboratory portion of the Introduction to Environmental Engineering course.*

Fitting All of the Pieces Together

The strategic scheduling of the individual lab activities and how they were grouped together in the different lab sets was an interesting optimization problem on its own. In some cases, activities were scheduled to coincide with broader themes/topics being covered by the lecture portion of the course. Within the first few lessons, the lecture introduces some of the "big picture" impacts of environmental engineering and the second week gives students practice with the types of concentration measurements we encounter in environmental sciences, when to use which type, how to convert between them, etc. – Lab Set I is intended to supplement these topics.

Lab Set II activities were all common to creating and using calibration curves. Students practiced graphing instrument response data and fitting a mathematical model to determine a calibration equation ("Making Calibration Curves"), they learned how to calibrate and use the field meter for measuring pH and conductivity ("Measuring pH and Conductivity"), and they took LaMotte Low Cost Water Monitoring kits (LaMotte Company, Chestertown, MD) and Hach 5-in-1 test strips (Hach, Loveland, CO) to practice using standardized colorimetric calibration curves to evaluate water quality parameters of a local source water ("Water Quality Kits"). In the lab, once students had become familiar with using the pH meter, we used the second half of the in-person lab period to reinforce chemical equilibrium by estimating required solution modifications (by adding hydrochloric acid or sodium hydroxide) to reach a target pH. In the lecture, acid-base equilibrium had been introduced in Week 4, so regardless of where it fell in lab schedule (i.e., Week 5, 8, or 9), all students had an equal exposure to the core concepts that were necessary. This was a key consideration when creating the schedule of activities, as a whole – I felt it was important to err on the side of moving activities later in the schedule, rather than earlier, in an effort to make the learning activity as equitable and effective as possible.

In other instances, activities were grouped simply by necessity, which was governed by what needed to take place in the limited physical lab space. For example, the Dissolution-Precipitation lab also explored concepts of chemical equilibrium, but in the schedule fell much later in the semester than the lecture material. Placed here, the activity was structured to focus on the experimental process itself – developing a procedure, determining material needs and calculations, gathering data, analyzing results, proposing procedural alterations for future experiments, etc. The technical content allowed students to again review chemical equilibrium, ultimately helping them prepare for the final exam and reinforcing that learning is, in fact, cumulative!

Thanks to some careful choreography, you will also notice that Lab Set III has two activities ("Turbidity + Stream Sampling" and "Dissolution-Precipitation") that each have two designated locations, allowing two groups of students to meet in-person for that day. While one group of students worked together in a nearby classroom to outline the necessary objectives and plan their approach to the Dissolution-Precipitation lab, another group of students was in the lab with me learning how to calibrate and use the portable turbidimeters. This second group then took their learned knowledge from Lab Set I to again prepare and calibrate the portable pH and conductivity meters. With the group for each activity working semi-independently, I was able to bounce between the neighboring laboratory and classroom to answer (and ask) questions for either group, help the Dissolution-Precipitation folks finalize their experimental procedures, etc. The Turbidity + Stream Sampling teams were then sent out into the field to gather direct turbidity, pH, and conductivity measurements from two locations on the creek that runs through campus. The Dissolution-Precipitation teams subsequently moved into the lab space where they proceeded with their own experimental exploration.

Embracing the Virtual Tools

While pandemic-based "HyFlex" or remote teaching may be a relatively novel concept, there is certainly a history of hybrid and online course delivery and the integration of virtual learning into engineering courses [5]–[11]. Several activities were carried over from previous semesters, but were tweaked to accommodate the adjusted modality. For example, the Policies and Regulations activity was originally designed as an in-person activity for small breakout groups of students to explore several prominent policies related to the environment and human health. Pairs or trios of students would select an individual regulation that they would like to spend 30-40 minutes of class time diving into with some cursory research. They would create a couple of presentation slides in a shared (i.e., class-wide) Google Slides document, including the primary objectives, history and motivations, significant impacts, etc. of their assigned policy. Students were encouraged to include images, links to additional reference materials, video clips, articles – anything they found interesting and worth sharing. The second half of the class period was used for groups to informally present their slides with the rest of the class, highlighting key points and facilitating a discussion with classmates about environmental milestones, movements, and events. The compiled slides ultimately created a study guide for students to reference throughout the semester and contained all of the additional resources (articles, videos, etc.) for them to explore independently.

The primary goal of the activity was to get the students engaged with topics within environmental engineering by giving them some context for the broader impact of environmental health and the roles that society plays in its destruction, repair, and/or maintenance. While this remained an important objective during our HyFlex semester, adding some assignment structure allowed this to easily transition to an asynchronous lab activity. Student parings were created in the learning management system, Canvas, and they used a Google Sheets spreadsheet to self-assign the regulation they would like to research. Instead of in-class exploration, students were given one week to work with their partner(s) to create their slides (again, in a collaborative class Google document) and submit a recorded video of their brief presentation. Videos were submitted to a class discussion board, created in Canvas. The second part of the Policies and Regulations activity allowed students to spend a second week viewing their classmates' videos and using the same discussion board to make comments, ask questions, etc.

I was ultimately thrilled with the student output for this activity. While it was still meant to be a relatively casual assignment, adding the structure of a formal discussion board and extending the time period improved the overall quality of student responses. Student reflections were robust and they often found links and made comparisons to other presented regulations. In several instances, something in the presentation triggered an interest and students would post additional resources or interesting articles that they had found after watching their classmates' video. Some sources provided conflicting information, which led to discussions on information bias, correlation versus causation, data analysis and interpretation, and the importance of reproducibility – certainly above and beyond the base objective of exploring some notable environmental policies and regulations. On the fundamental side of things, students practiced creating video presentations, concisely presenting information, efficiently searching for information, and critically evaluating the quality of information publicly available. While the COVID-19 pandemic was the primary reasoning this activity shifted to a virtual platform, the asynchronous and independent nature of the assignment ultimately led to a higher level of student engagement. While there are certainly in-person exercises that cannot be replaced, we should not be afraid to embrace virtual options when they open new doors for learning.

Removing the Recipe to Require Engagement

Many of us have taken, and probably taught, labs that require participants to follow a prescribed procedure to obtain some form of laboratory data. Similarly, there are plenty of assignments out there that follow a strict asked-and-answered format. While there is absolute merit to these activities – namely, the importance of strictly following procedures to develop reliable reproducibility – ambiguity and vagueness can also be an effective learning tool. There is support for reevaluating a traditional recipe-based procedure for content delivery and instead creating more open-ended problem solving [5], [6]. This is consistent with my approach to focus on skills building, tailoring assessment to learning outcomes, and providing exploratory opportunities for students, all of which became easier to facilitate with a smaller subset of students. By providing students with objectives for an end product, but leaving out the specific steps to reach that destination, they are required to forge their own pathway and rely on their developing scientific and engineering instincts. For example, the Measurements of Mass and Volume activity provided explicit instructions for how to properly use the various analytical balances and micropipettes as equipment, but the method used to create a one-molar or a 2% solution (including with what glassware, mixing technique, etc.) was entirely at the discretion of the student. Instead of simply following a recipe, putting this decision power with the student forces them to engage with the activity itself and to consciously evaluate *what* is actually being done and *how*. Their calculations and methods become more deliberate and they realize there is more than one "correct" answer.

Use Independent Activities to Facilitate Individual Learning
A key component of the rotational lab schedule was reducing the number of students in the physical lab space at a given time. As a result, exercises were often downsized to solo or paired activities. This completely eliminated any potentially idle time for any individual student – they were either fully controlling their individual exercise or they were an integral part of a two-person team. For example, in the Measurements of Mass and Volume activity, students were able to collectively brainstorm and ask classmates for help, but each student was required to make their own solutions. With labs that involve developing kinematic skills (e.g., pouring from a volumetric flask versus a beaker, scooping and weighing small masses of granular materials, weighing granulars in the presence of ambient static electricity), it is important that each student has an opportunity to flex each of those skills, instead of sharing the responsibility with a partner and potentially missing out on the experience entirely. For some lab exercises, it was more effective to have students work as a team of two (e.g., using the field meters to measure water quality parameters of the stream). The key here was to ensure that the activity required both students to be engaged (i.e., there was a "job" for each to do) and that the activity was repeated to provide at least one opportunity for the students to switch roles. For the stream sampling activity, this was accomplished by having teams collect data at two separate locations along the stream, maintaining the goal of having each student gain personal experience and practice with each component of the exercise.

Build Skills through In-Person Activities
Having a smaller number of students in the lab at a time also relieved previous equipment limitations. A more in-depth (i.e., highly repetitive) micropipetting exercise could be developed, which gave students the chance to not only try, but actually practice, a measurement technique that most had never been exposed to before. Instead of being given the opportunity to try pipetting a single volume before handing-off the micropipette to the next user, students were able to repeatedly pipette and hone this new skill. Using an adaptation of *Gee, Roy & Biv's Micropipetting Challenge* [12], students used electronic micropipettes of various volume ranges to pipette various volumes of water, concentrated food coloring, and form their own dilute mixtures, to create a series of vials that gradated across the visible color spectrum and total volume. While a seemingly simple exercise, developing muscle memory for pipetting is an asset for efficient laboratory work. Observationally, it was clear that as the students continued the exercise they grew more and more comfortable and they were able to work notably faster. By starting with adding water to vials, they could focus on holding, filling, and discharging the

pipette. Once that had been established, they could begin adding food coloring and the skill complexity could evolve to include being cognizant of cross-contamination, changing pipette tips, mixing, and accounting for more viscus fluids that could cling to the pipette tip's surface. By adding some very minor scaffolding to a seemingly easy activity, students are able to work toward mastery of a technique they will rely on for future lab work.

A second component of skills-building labs is to ensure that follow-up activities revisit those skills, which both gives them context and purpose, but also continually offers developmental practice. As was already mentioned, students learned to calibrate field meters in Lab Set I and then in Lab Set III they were able to go through that procedure again and expand on it by taking the meters out to actually take field measurements. The mass and volume measurement techniques practiced in Lab Set I were brought back for additional activities in both Lab Sets II and III. I also found that being open with students about the purpose of skill-building exercises generally seemed to make them more engaged with the activity itself. Students were more willing to embrace the learning exercise if they understood the focus was to learn how to safely perform necessary techniques using low-stakes chemicals (e.g., food coloring), in an effort to prepare them for future labs, courses, or even co-ops/internships where the environmental contaminants are unknown and potentially harmful – seeing the activity as an investment gave it meaningful purpose.

Shifting the Tone of Assessment

As with many aspects of teaching throughout the COVID-19 pandemic, there was a significant amount of uncertainty as faculty tried new tools, techniques, and ideas to engage our students – uncertainty of how well our vision would be executed, uncertainty of how many students might be suddenly quarantined and not able to fully participate, and the uncertainty of if/when we might be suddenly shifted to fully remote again. To accommodate this, and to alleviate the added mental, emotional, and physical burden students might have been feeling during this time, I took the opportunity to embrace alternative approaches for assessing their progress toward each activity's learning objectives.

As previously described, the Policies and Regulations activity gave students a chance to explore and follow their curiosity, without many prescriptive guidelines, so the resulting assessment (i.e., points awarded) was primarily based on their individual depth of participation. The Making Calibration Curves assignment, required students to linearly fit analytical data and use the resulting model and assigned reading to respond to directed questions about hypothetical experiments. Here, students were assessed based on their ability to think critically and provide reasonable explanations for their responses – this is a subtle but notable difference from evaluating if they responded "correctly." Because this activity was virtual and asynchronous, it was unreasonable to expect that they had completely mastered the concept independently, especially considering that for some students this might have been their first exposure to the concept. However, the Oxygen Demand activity was more of a reading comprehension assignment, so question responses should have been more direct and were assessed accordingly.

The Dissolution-Precipitation experiment was the perfect opportunity for students to write a traditional lab report. Students were tasked with creating magnesium carbonate, knowing that they had magnesium sulfate and sodium carbonate solids available. (Added bonus: because these compounds are Epsom salts and washing soda, respectively, both are readily available from a grocery store and any fully-remote students could easily participate, as well.) Outside of this, students had to fully develop the experiment – thinking through the required chemical reactions, desired solution concentrations, mixing ratios and techniques, what data to collect and how, and the resulting data analysis. Because they were given almost no details upfront, they *had* to provide a detailed report as the deliverable. To add another layer to the lesson, the low-risk nature of the activity removed the need for that idea of "correctness," again. If a portion of the procedure did not go as they had originally envisioned, students could make adjustments and restart, as needed.

For other in-person activities, I found it most effective to assess the students in real-time, which was only possible because I had a small number of them in the laboratory with me at a given time. For the micropipette skills activity, I could use the final color intensities and relative volumes to determine if they had made their solutions per the instructions – if a volume was low (usually due to carelessness) or if the color was weak (usually because they forgot to mix after additions before drawing from it again), we could have an easy discussion on the importance of best practices. A low-stakes assessment like this reinforced that the activity was about developing the skill itself and that the expectation is to make progress toward mastering a technique, not instant perfection.

In the second portion of the Measurements of Mass and Volume session, students practiced making various salt solutions of specified concentrations or percentages. Using a previously prepared calibration curve (an opportunity to tease the upcoming Lab Set II) for an ultraviolet spectrophotometer, I would measure their solution – if they were within 10% error of their target, students were allowed to proceed to the next mixture; otherwise, they had to try again. This approach had multiple advantages, some I had anticipated and others that were wonderful surprises. First and foremost, it gave students the opportunity to repeat the activity – again, this reinforces the objective of mastery and, as a Lab Set I activity, sets the tone for the remainder of the semester. Second, it provided a natural opportunity to have a discussion with the students about a variety of topics – students could share what they did differently from each other and often we could talk about the importance of glassware selection (e.g., volumetric precision of a beaker versus a volumetric flask), techniques to avoid spilling of both liquids and solids, instrument precision, replicate measurements, and instrument limitations (e.g., calibration range). Third, as with the micropipette activity, using low-risk and low-cost materials allowed students to make and correct mistakes along the way. As they get used to handling flimsy weigh paper, pouring from a thin-necked flask, or rinsing some clinging solids from a weigh boat, they knew that they could always start over, even before the official measurement test. Again, this shifted the focus to repetitive practice. Finally, the students thoroughly enjoyed a friendly competition for all the glory of having a solution with the lowest experimental error!

Debrief Loose Ends into Place

The rotational nature and small sizes of the lab groups (i.e., A, B, and C) allowed each group to have a somewhat unique lab experience, based on discussion tangents, temporal relation to the lecture material, etc. Additionally, by shifting a significant portion of the activities into a virtual, asynchronous, and/or independent modality, the instructor had to sacrifice the opportunity for direct observation, immediate feedback, and synchronous guidance of learning for these activities. To offset this, I used a course lecture lesson to embed a debriefing session at the end of each Lab Set. This served as an opportunity to somewhat "normalize" across the different lab sections and subset groups. For some activities, such as the pH and Conductivity in-person lab, this session was used to highlight some of the key concepts and solidify connections with the lecture material. For the Policies and Regulations exercise, I had taken some key talking points from the student discussion board to highlight particularly interesting comments and encourage further elaboration and discussion. We also used this time to specifically address the quality of source material – what type of publication is it, what are the qualifications of the author, what is the motivation/funding agency behind the article or video, etc.

The Water Quality Kits and Stream Sampling labs had the students measuring various water parameters from a local surface water source. Because of the continuous group rotation, we had regularly collected water quality data across nine weeks of the semester! For the debrief session, we looked at the compiled results to verify consistencies, identify anomalies, and compare the results to the presence of potential timely influences (e.g., weather). Where students might have previously been focused on using a written report to regurgitate a standard procedure and present a single data point with weak contextual connections, here they were able to fit their data puzzle piece into a larger picture and work collaboratively to hypothesize broader meaning behind it.

Evaluating Effectiveness of the Rotational Schedule

Outside of subjective feedback from the instructor and students, the relative newness of the program has made more quantitative comparisons with a pre-pandemic lab experience challenging. The first iteration of the Introduction to Environmental Engineering course and laboratory were run during the Summer 2019 semester, as the new laboratory space was being outfitted. The second iteration was the Spring 2020 semester, when our student body was moved fully-remote in early March in response to the COVID-19 pandemic, and the third iteration was delivered fully remote during the following Summer 2020 semester. (The fourth, and most recent, iteration would be the Spring 2021 semester, when this rotational schedule was implemented.) Because of the ever-evolving nature of the course until this point, it was difficult to find replicate activities and/or assessments that could be meaningfully compared in a quantitative way.

However, while the Spring 2020 cohort began their semester in person, they and the Spring 2021 cohort both took virtual final exams that were delivered in the same format with the same available resources. Each version of the final exam contained the same question requiring students to estimate dissolved concentration of the mineral gibbsite (i.e., aluminum oxide) in groundwater, given a particular pH. Both cohorts participated in synchronous and in-person pH and equilibrium (i.e., meter calibration and precipitation) lab exercises, with the Spring 2020 students working in groups of three or four students with a total of 16 in the lab space concurrently, and the Spring 2021 students of course in the rotational modality working individually or in pairs with no more than four students sharing the laboratory at a given time.

The average cumulative GPA at the beginning of the course was 3.31 for the Spring 2020 cohort and 3.32 for the Spring 2021 cohort. While both groups were exposed to the same lecture material, homework practice problems, laboratory exercises, and were ultimately given the same question on the final exam, the Spring 2021 cohort scored an average of 95% (median = 100%, range = 67-100%, N=33) for this pH/dissolution question, where the Spring 2020 cohort scored an average of only 79% (median = 85%, range = 15-100%, N=27). It is worth nothing that students were potentially in very different places, mentally, in May 2020 versus May 2021 and could have impacted their performance on a final exam. Additionally, a single data point is not substantial evidence for a definitive conclusion, but certainly points in a promising direction. Combined with the positive student feedback, it is a worthy endeavor to continue to develop and explore.

Moving Forward

A rotational laboratory schedule was implemented for the Spring 2021 Introduction to Environmental Engineering laboratory in an effort to accommodate the social distancing restrictions necessary to cope with the COVID-19 pandemic, while not sacrificing the individual, hands-on learning experience of students. As the semester progressed, it was clear that the overall approach was ultimately beneficial and more enjoyable, for both students and the instructor. Student learning was focused and personalized, allowing for inquisitive learning and development of laboratory skills. The instructor was able to take advantage of a smaller group of students in the lab to facilitate tailored discussions and provide more personal and immediate feedback.

Using the framework presented here, a comparable laboratory experience could be extrapolated for other engineering courses. After identifying a diverse list of target learning objectives, instructors should evaluate how individual objectives could be enhanced by the laboratory portion of the course. A key component of this would be classifying those that could benefit from a virtual and/or asynchronous exercise versus those that require in-person resources and guidance. Tangentially, instructors should evaluate how students will demonstrate mastery of each learning objective and scaffold a pathway for feedback and building skills, as necessary. While the COVID-19 pandemic has certainly introduced many challenges for higher education, it has also highlighted areas for growth and development by forcing innovation and surfacing nontraditional and underutilized pedagogy.

References

[1] C. Nikendei *et al.*, “Modification of Peyton’s four-step approach for small group teaching – a descriptive study,” *BMC Med. Educ.*, vol. 14, no. 1, p. 68, Dec. 2014, doi: 10.1186/1472-6920-14-68.
[2] J. Cooper and P. Robinson, “Small-group Instruction in Science, Mathematics, Engineering and Technology (SMET),” p. 12.
[3] K. A. Smith, “Going Deeper: Formal Small-Group Learning in Large Classes,” *New Dir. Teach. Learn.*, vol. 2000, no. 81, pp. 25–46, 2000, doi: 10.1002/tl.8103.

[4] A. Yazedjian and B. B. Kolkhorst, “Implementing Small-Group Activities in Large Lecture Classes,” *Coll. Teach.*, vol. 55, no. 4, pp. 164–169, Sep. 2007, doi: 10.3200/CTCH.55.4.164-169.

[5] R. M. Felder and R. Brent, *Teaching and Learning STEM: A Practical Guide*. John Wiley & Sons, 2016.

[6] P. C. Wankat and F. S. Oreovicz, *Teaching Engineering, Second Edition*. Purdue University Press, 2015. doi: 10.2307/j.ctv15wxqn9.

[7] R. Ochia, “A Hybrid Teaching Method for Undergraduate Biomechanics Lab,” *Biomed. Eng. Educ.*, vol. 1, no. 1, pp. 187–193, Jan. 2021, doi: 10.1007/s43683-020-00033-w.

[8] K. Woelk and P. D. Whitefield, “As Close as It Might Get to the Real Lab Experience—Live-Streamed Laboratory Activities,” *J. Chem. Educ.*, vol. 97, no. 9, pp. 2996–3001, Sep. 2020, doi: 10.1021/acs.jchemed.0c00695.

[9] R. Sell, T. Rüütmann, and S. Seiler, “Inductive Teaching and Learning in Engineering Pedagogy on the Example of Remote Labs,” *Int. J. Eng. Pedagogy IJEP*, vol. 4, no. 4, p. 12, Oct. 2014, doi: 10.3991/ijep.v4i4.3828.

[10] D. Oerther, “Reducing Costs While Maintaining Learning Outcomes using Blended, Flipped, and Mastery Pedagogy to Teach Introduction to Environmental Engineering,” in *2017 ASEE Annual Conference & Exposition Proceedings*, Columbus, Ohio, Jun. 2017, p. 28786. doi: 10.18260/1-2--28786.

[11] S. Frerich, D. Kruse, M. Petermann, and A. Kilzer, “Virtual Labs and Remote Labs: Practical experience for everyone,” in *2014 IEEE Global Engineering Education Conference (EDUCON)*, Istanbul, Apr. 2014, pp. 312–314. doi: 10.1109/EDUCON.2014.6826109.

[12] “Micropipette Challenge: Helping Gee, Roy, and Biv with their science lab.” Learning Undefeated, 2019. Accessed: Oct. 04, 2021. [Online]. Available: https://www.learningundefeated.org/wp-content/uploads/2019/01/Micropipette-Challenge.pdf